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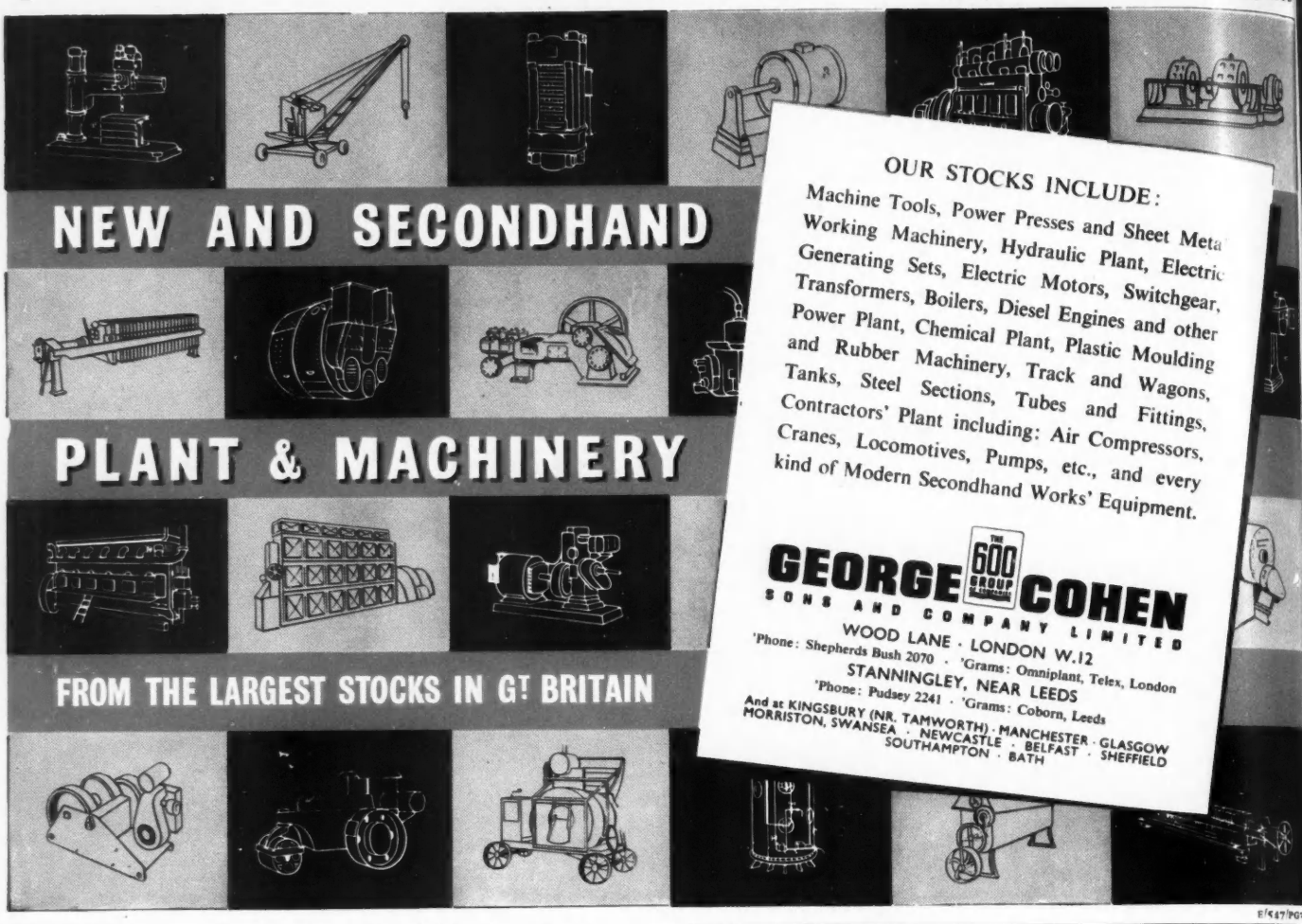
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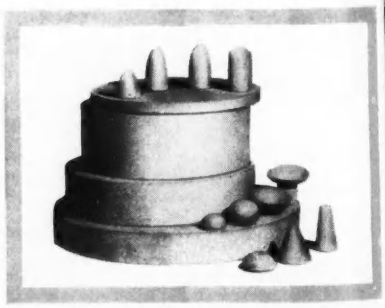

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THE ENGINEER

FEBRUARY 18, 1955

Industry and the New Towns

THE first factory to be built in the new town of Peterlee, County Durham, was officially opened on Friday last by Mr. William Deedes, the Parliamentary Secretary to the Ministry of Housing and Local Government. It was designed by Sir William Holford and Mr. W. M. Shennan and built by Bovis, Ltd., for the North Eastern Trading Estates, Ltd., to the requirements of Jeremiah Ambler, Ltd. In a speech at a luncheon following the opening of the factory Mr. Deedes said that he did not think that higher productivity was only to be won on the factory floor. A factory could not be separated from its surroundings, and good surroundings coupled with healthy, happy living conditions played a very important part in industrial efficiency. He referred to the progress of the twelve new towns in this country and said that despite their slow early growth steady progress was now being made. In these towns there were now nearly 28,000 new homes and the rate of building was increasing. In the eight new towns designed to relieve London there were now 131 new factories employing 18,000 people, and sixty-eight factories, which would provide work for a further 11,600 people were under construction. Mr. Deedes went on to say that the new towns were playing an essential part in meeting the challenge of the new age, and now in what might be considered the second industrial revolution of this country social conditions were in the forefront and not the background.

Measuring and Control Instruments for Efficient Combustion

LAST week the British Industrial Measuring and Control Apparatus Manufacturers' Association invited members of the Press to an exhibition of instruments and apparatus designed to promote fuel efficiency and reduce atmospheric pollution. The exhibition was prompted by the moves now being made towards the elimination of smog in cities. Opening addresses were given by Mr. W. G. Thomas, vice-president of the association. Sir Ernest Smith, the president of the Smoke Abatement Society, and Mr. L. Clegg, the chief engineer of the National Industrial Fuel Efficiency Service. The speakers stressed the importance of adequate instrumentation to provide the information and means of control necessary for the efficient operation of furnaces and boiler plant. It was pointed out that in order to obtain the fullest benefit from such recording and control instruments furnace operators required to be trained in their efficient use. It was considered that the minimum equipment needed on every boiler plant included a draught gauge, a CO_2 or O_2 recorder or indicator ; a flue gas temperature recorder or indicator ; and a smoke density alarm, indicator or recorder. A selection of these and other relevant instruments was shown by a group of manufacturers belonging to the association. In offering the services of its specialist members in connection with smoke problems and efficient combustion the association drew attention to the fact that a survey of a cross-section of industry showed that the average saving which could be effected in the process steam used was 21 per cent, to which proper control with the correct instruments contributed very largely.

United Nations Technical Assistance

THE Federation of British Industries has published a report entitled " United Nations Technical Assistance," which has been compiled as the result of visits by two teams to the United Nations Technical Assistance Administration in New York and the Food and Agriculture Organisation in Rome. Both teams were accompanied by Sir Norman Kipping, director-general of the Federation of British Industries. The report emphasises that technical assistance, by which the developed countries offer aid to the less developed so that standards of living can be raised, has become an increasingly important factor in the post-war world. The methods principally used are the provision of experts to visit the receiving country to give technical advice, the selection of men from receiving countries to be given training in developed countries, and the provision on a small scale of demonstration and training units in underdeveloped countries. The report says that the concept of technical assistance is in general politically and economically sound, but that too little is known about it. The working and financies of the United Nations agencies are described and some interesting examples are quoted in the report of what has already been achieved in some of the less developed countries through technical assistance. It is also urged that the British Government should give a lead to other countries by announcing the scale of the support it will give to the United Nations expanded technical assistance programme at least two years ahead. There are then some recommendations made for improved liaison between the technical assistance agencies and British industry. The teams say that what surprised them during their visits was how little they knew of what was going on. Repeatedly they heard about individual problems towards the solution of which they could give advice or help. This experience, the report comments, led the teams to feel dissatisfied with United Kingdom liaison arrangements. The suggestions made include the setting up by the Federation of British Industries of a panel to concern itself particularly with the " follow-through " of technical assistance projects. The view expressed in the report is that there are many technical assistance projects for which the offer of really good experts from the United Kingdom is most desirable.

National Institute of Agricultural Engineering

THE National Institute of Agricultural Engineering has just published a report of its work during the year ended September 30, 1953. It gives some account of the experimental, development and testing work undertaken by the Institute at its headquarters at Wrest Park, Silsoe, and at the Scottish Machinery Testing Station at Calder. In some instances information has now been published as to the progress of some of the Institute's projects beyond the period dealt with in the report, but that does not lessen the interest and usefulness of the record. In the section which deals with the work of the testing department, for example, it is noted that during the year under review twenty-seven test reports on twenty-one different kinds of machines were issued. Of those reports, six were concerned with ploughs and cultivation equipment, four with harvesting machinery, three with hammer mills, and three with sowing and planting appliances. The remaining eleven reports dealt with ten different kinds of machines or devices. The report explains that data on the relative merits of different testing and sampling methods, and on the range of conditions under which a test should be carried out, are obtained from previous tests, from current testing work, and from special investigations initiated for the purpose. All the accumulated information on each technique is recorded whether a particular method is considered to be satisfactory or not. At the same time a " recommended " or " preferred " test procedure is laid down, and it is this preferred method which forms the basis for future routine tests. The report says that, at the moment, it is not the department's aim to produce a standard test for each class of machine or implement, as has been done in the case of tractors, since the rather variable requirements of test entrants and the need for carrying out tests under special or unusual conditions tends to preclude any such standardisation at present.

Power Farming Conference

THIS week the fifth National Power Farming Conference is being held at Harrogate. It is a conference which brings together agricultural machinery designers, manufacturers and dealers and farmers from all parts of the country for discussion of their problems. The principal theme of this year's conference is mechanical handling on the farm and several of the papers deal with various aspects of that subject. A paper of particular interest to engineers was one entitled " Profit or Loss on Machinery," which was presented on Wednesday by Mr. Frank Henderson. Mr. Henderson treated his subject from the agricultural machinery user's standpoint, and said that he had never bought a machine to save labour, but only to increase production per person employed. If by farm mechanisation simply physical effort was saved, Mr. Henderson argued that the cost of production would be increased and also the mental strain, for, he observed, mechanisation involved worry and trouble quite apart from any financial consideration ! Mr. Henderson went on to say that he had been buying new machinery for over thirty years, and, with the notable exception of tractors, had yet to have a machine delivered which could be used effectively without some alteration, adjustment or repair before it could start work ! He therefore appealed to makers to check their machines before they sent them out. Mr. Henderson also urged that machinery makers should pay more attention to instruction books. He said that if farmers were to be ready buyers they would have to be given really good instruction books, both for assembly and for running the machine.

Royal Society of Arts Prizes

THE Royal Society of Arts has announced some particulars of endowed prizes which it is offering in the present year. The first of them is the Howard Prize, established in 1868, for periodical award to the authors of treatises on " steam or other motive agents." The prize of £50 will be awarded this year to the author of a treatise on some aspect of the subject of mechanical motive power. Another prize, to a value of £20, is available under the terms of the Benjamin Shaw trust, which was founded in 1876 " for the promotion of improvements in all matters relating to unhealthy and dangerous occupations." This year the prize is offered for any discovery, invention, or newly-devised method of obviating or naturally diminishing any risk to life, limb or health, incidental to any industrial occupation, and " not previously capable of being so obviated or diminished by any known and practically available means." Entries for this prize may be in the form of descriptive essays or models. Finally, there is the Fothergill Prize, valued at £20, which is offered for a descriptive essay or model embodying some new idea for the prevention or suppression of fire. Entries for these prizes must be received by the Secretary of the Royal Society of Arts, John Adam Street, Adelphi, London, W.C.2, not later than July 31st next. The Society says that it cannot accommodate bulky models for judging. Such entries must be submitted by written descriptions or models, though the Society may subsequently require a demonstration with the actual apparatus.

High Power Spark Erosion Machine

By L. R. BLAKE, Ph.D., B.Sc. A.M.I.E.E.

Most spark erosion machines commercially available employ the resistance charged capacitance relaxation circuit, with servo control of the cutting electrode. This circuit has an inherently low electrical charging efficiency, which virtually restricts its use to low cutting powers, and the need of the servo control leads to expense in the machine. The first disadvantage has been overcome by charging the capacitor through an inductor which is also used as a vibrator of the cutting electrode to ensure repeated and reliable discharge of the capacitor at peak electrical energy. Partially counterbalancing the vibrator head allows the cutting electrode to advance under gravity and eliminates the need for servo control. A circuit breaker with overload trip in the charging circuit is used for rapidly clearing short circuits between tool and workpiece and permits the cutting power to be maintained at a high value. In a simple prototype machine, cutting speeds of 0·5 c.c./min with tungsten carbide and 2 c.c./min with "Nimonic 80" have been attained at 8·8kW input and 95 per cent electrical charging efficiency from an 80V d.c. supply.

The Resistance Charged Relaxation Circuit

THE most common circuit of spark erosion machine tools already available in Europe and the United States is the resistance charged relaxation circuit[1] shown in Fig. 1 (*a*). In this circuit direct current supplies are used of about 30V to 200V and values of capacitance C of 10 to 1000 microfarads. If no spark occurs between cutting electrodes and workpiece the condenser charging voltage assumes the familiar exponential forms shown in Fig. 1 (*b*). However, if the tool is held at about 0·001in to 0·004in from the workpiece, the condenser is prevented from fully charging to the supply voltage by repeated sparkovers between the electrodes, when the condenser charging voltage V_c and current I_c become as shown in Fig. 1 (*c*). Characteristics of this circuit are the irregular value of the capacitor discharge voltage and a tendency for the electrodes to remain in contact after discharge, preventing the rapid recharging of the condenser.

The electrodes are maintained at the desired sparkover distance by a servo-control system, shown diagrammatically in Fig. 1 (*a*), in which the output from the amplifier drives the motor in such a direction as to make its input voltage zero, or, in other words, the mean gap voltage equal to an adjustable reference voltage. Thus the reference voltage controls the mean value of the capacitor voltage and the mean discharge repetition rate.

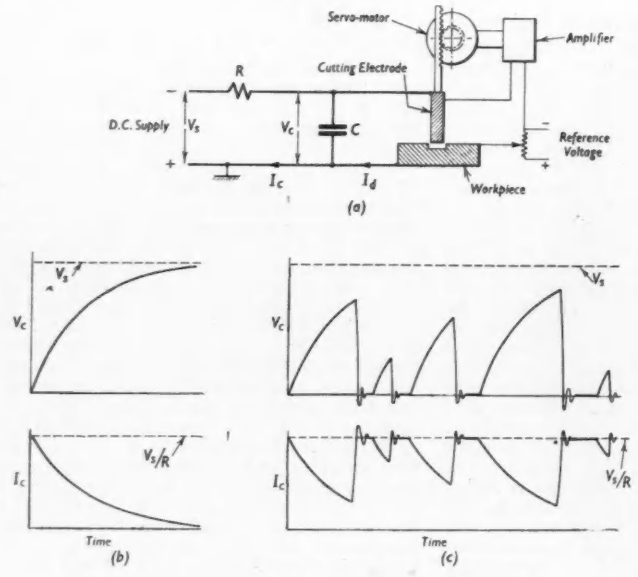
In this circuit the maximum electrical charging efficiency possible (that is, the ratio of capacitor power to input power) is 50 per cent, provided the capacitor fully charges each cycle. Under these conditions, however, the discharge rate and capacitor power tend to zero, so it is better to arrange operation for maximum capacitor power, which is achieved if the capacitor is regularly discharged at 71·5 per cent of full voltage ; the charging efficiency is then 35·8 per cent and the capacitor (or cutting) power $V_s^2/5R$ approximately. However, as there is no mechanism to ensure discharge at the optimum voltage value, it is not possible to realise this optimum output power ; moreover as the cutting electrode often remains in contact with the workpiece after a discharge, as indicated by the delay in recharging in Fig. 1 (*c*), power is dissipated in the charging resistor and the charging efficiency also drops to a low value. This low efficiency, not particularly important at low cutting power, becomes most undesirable at high power, as can be appreciated when it is realised that at 10kW cutting power, for example, 40kW may have to be dissipated in the charging resistor.

Some of the disadvantages of the resistance charged circuit can be overcome by applying constant current, short period pulses to the electrodes from a pulse forming network, as referred to by Williams, Woodford and Smith in a recent paper,[2,3] but, as stated there, these machines "are invariably more costly in design and manufacture than relaxation machines" and so will not be considered further. The disadvantages are much more simply overcome by the use of inductance charging methods.

The Inductance Charged Circuit

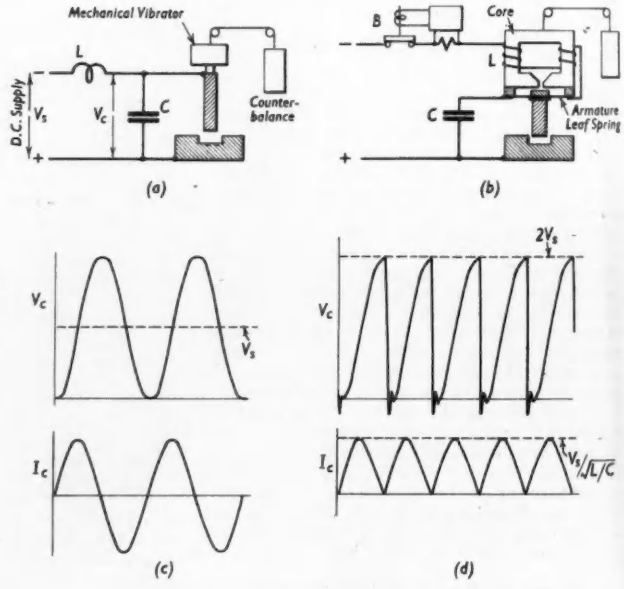
Consider first the charging voltage and current waveforms of a simple inductance-capacitance series circuit when connected to a constant voltage supply. As shown in Fig. 2 (*c*), the capacitor voltage rises to oscillate about the supply voltage V_s and the current is a sinusoidal oscillation of peak amplitude $V_s/(L/C)^{\frac{1}{2}}$. (In practice, of course, due to unavoidable resistance in the charging circuit, the oscillations die out, leaving the capacitor fully charged and the current zero.) For best operation it is desirable to trigger the discharge to occur at the first voltage maximum, when the capacitor voltage is virtually twice that of the supply. This can be done by vibrating the cutting electrode at twice the natural frequency of the LC charging circuit, as indicated in Fig. 2 (*b*). Sparkover occurs just before the electrodes make physical contact (as evidenced by the characteristic arc drop shown in Fig. 5 later), and the discharge occurs regularly at precisely spaced intervals, as indicated in Fig. 2 (*d*).

With this technique of inductive charging and tool vibration, it is possible to achieve automatic progression of the cutting electrode in a very simple way by partially counterbalancing the vibrating head and allowing it to fall under gravity, when the cutting action will continue unattended. The cutting electrode strikes the workpiece and rebounds each cycle, somewhat in the manner of a pneumatic drill ; thus some mechanical forces come into play, but they are not large



(*a*)—Typical resistance-charged relaxation circuit with servo control of electrode position indicated diagrammatically.
(*b*)—Exponential rise of capacitor voltage and decay of charging current in a simple R-C circuit.
(*c*)—Relaxation oscillations which occur when the cutting electrode is held close to the workpiece.

Fig. 1—Resistance-charged relaxation circuit



(*a*)—With separate mechanical vibration of the tool and partial counterbalancing of vibrating head for automatic tool progression under gravity.
(*b*)—With combined charging inductor and tool vibrator. Contactor is to temporarily interrupt charging current, causing vibrator to mechanically break short.
(*c*)—Oscillatory rise of capacitor voltage and decay of charging current in a simple L-C circuit.
(*d*)—Typical capacitor voltage and current curves for circuit (*b*).

Fig. 2—Inductance charged circuits

if counterbalancing is nearly complete. Although physical contact at each discharge is unavoidable, it does not seriously reduce the charging efficiency as before, for, with inductive charging, the current is low at the beginning of the charging cycle and what charging energy is involved is mainly stored in the charging inductor, to be returned to the capacitor when the electrodes separate ; this is evident in oscillograms by the initial rapid rise of capacitor voltage.

A particularly simple arrangement is to combine the function of charging inductor and vibrator in a single unit, as indicated in Fig. 2 (*b*). A machine embodying this arrangement is illustrated in Fig. 3. The attractive force on the armature of such a vibrator is proportional to the square of the charging current (the current is shown in Fig. 2 (*d*) to be a rectified sine wave), and so is sinusoidal and its frequency is twice that of the *LC* charging circuit, as required. The armature displacement is in phase with the magnetic force and the desired electrode movement is achieved, provided the natural vibration frequency of the mechanical system $f_m=1/2\pi(Kg/M)^{\frac{1}{2}}$, where K is the spring stiffness and M the vibrating mass, is high in comparison with the frequency of the magnetic force $f=1/\pi(LC)^{\frac{1}{2}}$. In practice, excellent operation is obtained when operating at or even above the mechanical resonance frequency, although the capacitor then tends to be discharged at a voltage beyond and below its peak value. To obtain the required vibration amplitudes of the order of $\pm 0{\cdot}01$in at high frequences inevitably involves operating close to the mechanical resonance frequency.

Another point indicated in Fig. 2 (*b*) and (*d*) is a method of clearing short circuits between cutting electrode and workpiece, which have a tendency to occur occasionally and which limit the power that can be employed and hence the rate of cutting. If a short circuit occurs in this circuit the current rise is of the form $(V/R)(1-e^{-Rt/L})$, where R is the resistance of the complete circuit including the charging inductor and the electrodes. The maximum value is much in excess of the peak current to be expected under ordinary working conditions, $V/(L/C)^{\frac{1}{2}}$. This is no disadvantage, however, for excess current can be used to trip the circuit breaker B when the short circuit is automatically broken. This result is produced as follows. When the current in the inductor-vibrator is interrupted, the armature gap, which was fully closed, begins to open under the action of the spring. The cutting electrode is stationary, bearing against the workpiece, and the core is pushed upwards and overswings, when it then pulls up the electrode and probably breaks the short circuit. The breaker closes again as quickly as possible when the armature is again attracted to the core, pulling this time on the cutting electrode against the inertia of the core and coils, again tending to break the short circuit if it still exists. By this means it is possible to clear a short circuit in a few milliseconds, and so prevent an appreciable reduction in the machining time. Even during a short circuit much of the electrical energy is stored in the charging inductance and is released to the capacitor when the short is cleared.

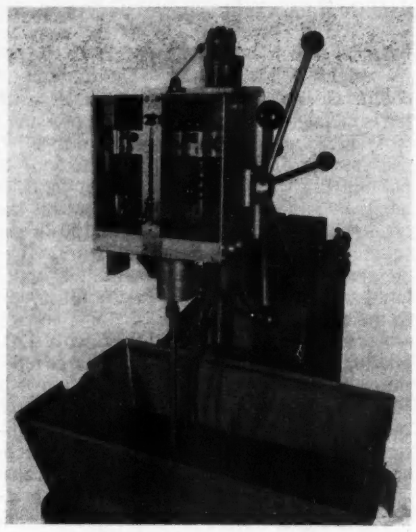


Fig. 3—Prototype drilling machine with cover removed to show inductor-vibrator head, capable of 12kW operation at up to 500 c/s vibration frequency

Characteristics of the Inductive Charging Method

It is now possible to summarise the characteristics of the inductor-vibrator method of spark erosion, and to make comparison with the resistor-servo method where appropriate.

(*i*) *Cost.*—The inductor-vibrator method has the advantage both in the cost of the machine and in running costs. The machine cost is smaller because the individual electrical components have a rating not much greater than the cutting power itself (conveniently measured as $\frac{1}{2}CV_d^2f$, where V_d is the capacitor voltage at discharge and f the discharge repetition rate). In particular this fact brings about a marked reduction in size and cost of the a.c. mains transformer and rectifier, which, with inductive charging, needs a rating only slightly larger than the cutting power whereas, with resistive charging, it can be more than five times as much. As shown later, it is also possible to employ a.c. charging and so eliminate the need for a rectifier altogether, but, as this necessitates making the discharge repetition rate the same as the supply frequency, it is not always convenient when a high frequency is required. A further saving is the cost of the servo control for the cutting electrode, although this gain is offset by the cost of the inductor-vibrator.

As there is no difference in the actual mechanism of erosion, the running costs of the two methods can be compared by the charging efficiency which, with resistive charging, is probably no better than 20 per cent, and, with inductive charging, is usually in excess of 95 per cent, depending on the discharge repetition rate.

(*ii*) *Cutting Speed and Cutting Power.*—As found by Williams, Woodford and Smith, fouling of the dielectric fluid in the sparking gap is the chief limitation to cutting speed ; not so much directly, since with rapid fault clearance, the cutting rate is not altered appreciably even though the number of short circuits may be many, but indirectly, due to the marked deterioration in surface finish due to the shorts. However, with inductive charging the cutting power has been taken to 10kW, whereas a tenth of this figure or even less is more normal with resistive charging. A high erosion efficiency with not much more than normal electrode wear has been obtained at this power when cutting tungsten carbide with several cutting electrode materials including brass. Cutting speeds of 0·5 c.c. per minute with tungsten carbide and 2 c.c. per minute with " Nimonic

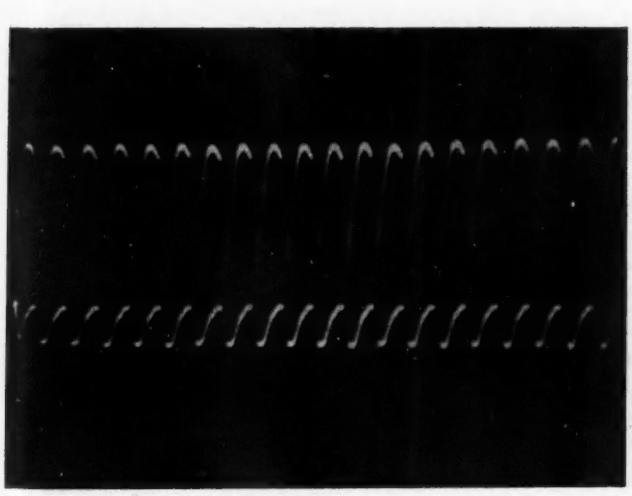


Fig. 4—Oscillogram of capacitor voltage (upper) and charging current (lower) at 7kW cutting power (1700 microfarads, 390 c/s 145V at discharge)

Fig. 5—Oscillogram of electrode voltage (lower) and discharge current (upper) at 0·7kW cutting power (1700 microfarads, 350 c/s repetition rate, 42V at discharge)

80" as workpiece materials present little difficulty for milling and turning operations, although such speeds are not so easily realised when drilling deep holes, because of the inability to clear away the eroded particles.

(*iii*) *Versatility.*—A wide range of cutting power and speed of machining is possible, so that the surface finish can be easily regulated. Power can be changed by alteration of the applied voltage or by reduction of discharge capacitance. For example, no difficulty is encountered in reducing the supply voltage with maximum capacitance from 100V down to 15V, and a wide range of capacitance can also be employed, despite the fact that this changes the vibration frequency and the vibration amplitudes. The machine is similarly accommodating to change of electrode size over a wide range, the upper limit being when the vibration amplitude becomes too small, and the lower limit when the cutting electrode becomes too fragile to withstand the force of collision with the workpiece each cycle. To increase the range of a particular machine, different vibrating heads can be used for different classes of work and tool size. It is possible, however, that very small diameter holes are more readily dealt with in a machine with servo controlled tool progression.

(*iv*) *Application to Different Kinds of Machine Tool.*—Spark erosion with inductive charging and tool or workpiece vibration can be applied to most of the normal machining operations, such as drilling, milling, grinding, turning, boring, planing, or sawing with bandsaw or circular saw. The main problem to solve in each application is the method of forced circulation of the dielectric fluid to the cutting face under high pressure and flow conditions to ensure the rapid removal of the eroded particles and so to permit the use of a high cutting speed with good surface finish. There will be some differences between machines because of the suitability of different arrangements, such as vibration of cutting electrode or workpiece ; combined charging inductor-vibrator or separate mechanical vibration, or even rotated segmented electrodes ; counterbalancing or spring pressure for automatic electrode progression, or the use of a constant torque motor, or hydraulic control, or manual control ; a.c. or d.c. charging, and so on.

12kW Prototype Drilling Machine

The prototype of a drilling machine with a maximum continuous rating of 12kW is shown in Fig. 3. The inductor-vibrator head is mounted within a steel case on eight ball bearings which roll on triangular guides to allow vertical movement without side play. The core of the vibrator is of grain-oriented silicon iron and the armature is of "V-Permendur" to give maximum magnetic force with the minimum armature weight. Two 2½in by 0·092in strips of phosphor bronze form the leaf spring having a stiffness of 40,000 lb per inch ; the mechanical resonance frequency is about 500 c/s, but depends, of course, on the weight of the tool. Values of charging capacitance of up to 1700 microfarads are employed and, since the vibrator inductance is 120 microhenries with about the same again in the rest of the charging circuit, this makes the natural frequency of the charging circuit 200 c/s. In operation the discharge frequency is 350 to 400 c/s. The tool holder has a side entry for the dielectric scavenging fluid, and slides in an "Oilite" bush. The hand-wheel drives a rack and pinion to lower the electrode on to the workpiece and to act as an over-riding hand control which is particularly useful when breaking through a hole. The wire from the vibrator passes over the pulley wheel on the drill column to the counterbalance, which is left accessible to permit its weight to be adjusted. The amount of counterbalance required for automatic drilling is mainly dependent on the fluid pressure.

At high cutting power, transformer oil is used as the dielectric fluid in preference to paraffin but the suitability of other fluids is being examined. A gear pump controls the oil flow, and a relief valve set at 150 lb per square inch prevents excess pressure. The oil pressure is normally kept at this upper limit. A filter is included in the oil circuit to the cutting electrode.

At a cutting power of 12kW with 1700 microfarads capacitance and a discharge repetition rate of 350 c/s, the supply voltage is 100V, the capacitor discharge voltage almost twice this figure and the mean charging current is 120A. The peak value of the discharge current is a little less than 6500A. This value is calculated from the easily derived expression $(V_d - V_{arc})/(L_d/C)^{\frac{1}{2}}$ with the following values : discharge voltage V_d, 200V ; arc drop V_{arc}, 20V ; discharge circuit inductance L_d, 13 microhenries ; capacitance C, 1700 microfarads. Making allowance for the resistance of the discharge circuit, the r.m.s. value of the discharge current is 2000A. It is evident that the condenser duty is very arduous.

Table I shows the results of cuts at 2kW and 10kW cutting powers with different workpiece and cutting electrode materials. Spark erosion efficiency is tabulated (measured in terms of micrograms of workpiece eroded per second per watt of cutting power, i.e. micrograms/joule) ; the table also shows the cutting rate and the relative electrode/workpiece wear. The cutting rate is included in the table for convenience, although it can be simply deduced from the erosion efficiency.

Table I shows that although a fairly high erosion efficiency is maintained up to 10kW in many materials, so that the cutting rate increases with the cutting power, this is not so with brass cutting tungsten carbide or tungsten. In this case, the cutting rate remains fairly constant from 6kW to 10kW, the figures at 6kW, for example, being :

	Workpiece material	
	Tungsten carbide	Tungsten
Micrograms/joule	12·3	7·7
C.c./minute	0·30	0·15
Wt. electrode/wt. workpiece	3·8	5·9

Another fact which emerges from Table I is that steel makes a poor cutting electrode, with low erosion efficiency and a high wear rate, while tungsten is a very efficient cutting electrode. Unfortunately, tungsten will not find wide application as a cutting electrode because of its high price and because of the difficulty in obtaining it in the required shape or form, but there is a possibility that it could find application in a bandsaw in wire form, which is available though costly. Table I also shows the ease with which "Nimonic" can be machined, a cutting rate of 1·9 c.c. per minute being achieved with a brass electrode. As a further example, a hole ⅜in diameter was drilled through a ½in "Nimonic" plate in eight seconds using a tungsten electrode.

Apart from the fall in erosion efficiency with cutting power, which sets a limit to the cutting power which can usefully be employed, a further limitation is the incidence of short circuits between cutting electrode and workpiece which causes rough running and a marked deterioration in the surface finish. Short circuits begin to become troublesome at powers above about 2kW with brass and above 10kW with tungsten cutting electrodes ; however, short circuits can be prevented, at least up to 10kW with all the cutting electrode and workpiece materials mentioned in Table I, by careful control of the downward force on the tool —that is, the counterbalanced weight to the head. In the tests, short circuits are counted with a message register which indicates the number of contactor operations.

In Fig. 4 is shown an oscillogram of the condenser voltage and charging current of the spark eroder operating at 7·0kW power,

TABLE I—*Spark Erosion Results*

The following results were obtained with various cutting electrode and workpiece materials at 2kW and 10kW cutting power and about 0·1in deep cuts with ⅜in to ½in diameter tubular electrodes with approximately 1/16in thick walls. Test conditions : 1700 microfarads, 350 c/s repetition rate approximately, transformer oil at 150 lb per square inch.

Cutting Power 2kW

	Cutting electrode	Workpiece (density)					
		Brass (8·40)	Mild steel (7·92)	"Nimonic 80"[1] (8·29)	Tungsten carbide[2] (14·7)	Tungsten carbide[3] (10·8)	Tungsten (19·0)
Erosion efficiency (μgm/joule)	Brass[4]	18	12	35	18	10	13
	Mild steel[5]	22	5·0	16	8·5	7	6
	Tungsten	59	23	31	20	—	26
Cutting rate (c.c./min.)	Brass	0·26	0·18	0·51	0·15	0·11	0·08
	Mild steel	0·31	0·07	0·24	0·07	0·08	0·04
	Tungsten	0·8	0·36	0·47	0·16	—	0·16
Wt. electrode / Wt. workpiece	Brass	4·2	4·0	1·0	3·1	5·0	4·6
	Mild steel	1·4	13	3·5	7·4	6·5	8·0
	Tungsten	0·08	0·8	0·44	1·3	—	0·8

Cutting Power 10kW

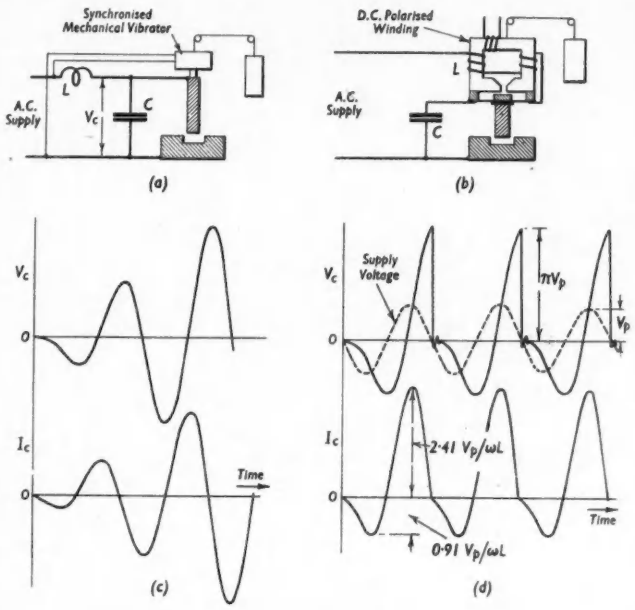
	Cutting electrode	Workpiece (density)				
		Brass (8·40)	Mild steel (7·92)	"Nimonic 80"[1] (8·29)	Tungsten carbide[2] (14·7)	Tungsten (19)
Erosion efficiency (μgm/joule)	Brass[4]	18	10	26	7	4·3
	Mild steel	17	14	—	8	4·5
	Tungsten	28	17	30	12	15
Cutting rate (c.c./min.)	Brass	1·3	0·8	1·9	0·28	0·14
	Mild steel	1·2	1·0	—	0·33	0·14
	Tungsten	2·0	1·3	2·2	0·50	0·47
Wt. electrode / Wt. workpiece	Brass	3·5	3·4	0·9	4·8	9
	Mild steel	2·0	3·4	—	4·9	8
	Tungsten	0·07	0·55	0·24	1·4	1·1

[1] An 80 per cent Ni, 20 per cent Cr based alloy.
[2] 92 per cent WC, 8 per cent Co.
[3] 76 per cent WC, 18 per cent TiC, 6 per cent Co.
[4] Density 8·49 gms/c.c.
[5] Cold drawn weldless annealed steel tube B.S. 806 : 1954, Pipes class "A."

with tungsten cutting electrode and workpiece. The regular discharge even at this high power can be seen, which follows closely the predicted waveforms shown in Fig. 2(*d*).

In Fig. 5 is shown an oscillogram of the discharge voltage between cutting electrode and workpiece and the discharge current, using a brass cutting electrode and tungsten carbide workpiece at 610W cutting power. The voltage measuring connections were made close to the gap and the discharge current was measured using the hollow brass cutting electrode as a non-inductive shunt. The characteristic arc drop, just before physical contact is made between the electrodes, is clearly shown. The peak discharge current is 680A and the discharge voltage 45V; the arc voltage is 24V falling to 13V. Very similar oscillograms of the arc drop and discharge current were obtained in experiments using single discharges.

In single discharge experiments it was found that sparkover occurred at a surprisingly large gap separation, the average distance being 0·001in at 40V rising to 0·003in at 200V, with wide variations about the mean from less than 0·0001in to 0·005in. Under repetitive discharge conditions the arc distance is clearly not very variable, as evidenced by the steady value of the discharge voltage. It is possible, therefore, that either the arc occurs regularly at a lower gap distance than obtained in the single discharge experiments, or that there is actual physical contact between filamentary highspots which vapourise to form an arc before low resistance electrode contact is made.



(*a*)—With separate mechanical vibrator synchronised to a.c. supply.
(*b*)—With combined charging inductor and tool vibrator, with magnetic polarisation of the core provided by d.c. winding.
(*c*)—Oscillatory rise of capacitor voltage and charging current in a simple *L-C* circuit.
(*d*)—Waveforms when tool is vibrated on workpiece.

Fig. 6—Inductance charging direct from an a.c. supply

Limits to Cutting Speed

The cutting speed is limited mainly by the surface finish and accuracy required, both of which deteriorate gradually with increase in power up to a point where short circuits begin to appear, when there is a marked deterioration.

It is possible to improve the surface finish at a particular cutting power below the critical value by lowering the energy per discharge and raising the discharge repetition rate, but there is an upper limit to this when mechanical vibration is involved as in the present method. Using a magnetic armature having a ratio of magnetic force to weight of 1000 as in the prototype drilling machine, which is about the maximum ratio possible, it is very difficult to obtain a vibration frequency in excess of 1000 c/s, with a vibrating mass of 2 lb and an amplitude of ±0·01in. Higher vibration frequencies than this might be employed in special cases, for example, when the workpiece is very small and could be vibrated instead of the tool.

To extend the critical cutting power at which short circuits begin to appear, the most hopeful course appears to be greater pressure and flow of the dielectric scavenging fluid, and improved electrode materials. The ideal cutting electrode should possess a low wear rate and be cheap and easily obtained in the required form; it must also have a reasonably good electrical conductivity.

Apart from these considerations, there is little doubt that the cutting power can be increased well above 10kW by increase of the discharge capacitance and voltage, subject to the limitation indicated by tests below 10kW, that the erosion efficiency tends to fall with increase power and the tool wear to increase, though there are exceptions to this rule.

A.C. Charging

If the inductor-vibrator is polarised using an auxiliary d.c. excited winding, or permanent magnets, it is possible to operate directly from an a.c. source instead of d.c., as indicated in Fig. 6. To do this, the natural frequency of the charging inductance and capacitance, $f=1/2\pi(LC)^{\frac{1}{2}}$, is made equal to the supply frequency. Under these conditions the capacitor voltage builds up in an oscillatory manner, assuming it is not limited by electrode discharges, the first voltage peak being $\pi/2$ times the supply voltage peak, the second maximum π times, and so on, the sign of each maximum alternating, as in Fig. 6 (*c*). To ensure that the workpiece is always positive at the discharge it is desirable to trigger the discharge to occur at the second voltage maximum. This can be done by vibrating the electrode at the supply frequency, using an auxiliary vibrator as in Fig. 6 (*a*), or using a combined inductor-vibrator as in Fig. 6 (*b*), where in this instance the vibrator is polarised to make its frequency that of the magnetising current, and not twice the value as in the d.c. case.

A machine operating on this principle has been made and operated successfully, and an oscillogram of the capacitor voltage and charging current is shown in Fig. 7. In this particular machine the circuit was modified by using a main charging inductor in series with the combined inductor-vibrator which was shunted by a rectifier to obtain a polarised characteristic.

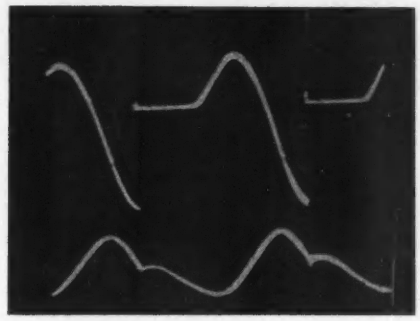


Fig. 7—Oscillogram of condenser voltage (upper) and charging current (lower) with a.c. spark erosion machine

When employing a separate mechanical vibrator care has to be taken, in the a.c. charging case, to phase the vibration with respect to the supply voltage; in the d.c. case it is only necessary to choose a vibration frequency reasonably close to the natural frequency of the charging inductance and capacitance.

In general it does not seem worth while to operate at the low discharge repetition rate corresponding to the power mains frequency of 50 or 60 c/s, although such a machine would be cheap and is very accommodating in its operating characteristics. However, due to the fact that the mean condenser voltage can be made zero, a.c. operation does allow a matching transformer (with low leakage reactance) to be connected between the charging condenser and the electrodes so that a high voltage, low capacitance, discharge capacitor can be employed giving a rapid discharge frequency, yet with the electrode voltage at its optimum value. A matching transformer is not possible with d.c. charging without synchronous switching of the transformer primary in and out of circuit, since the mean capacitor voltage is not then zero. Unless the a.c. supply frequency is high, however, the matching transformer is undesirably large, since its rating is determined by the mean condenser voltage and the r.m.s. value of the discharge current which, as already pointed out, is much in excess of the r.m.s. charging current. A high frequency, alternator excited, inductance charged circuit with transformer matching between condenser and electrodes may prove useful for high cutting powers.

Conclusions

Spark erosion machining has many features peculiar to itself. Due to the absence of rotary motion of the cutting electrode, for example, holes of irregular section can be drilled or holes with curved axes, and complex patterns can be engraved. Due also to the absence of mechanical forces at the cutting faces, the workpiece is left in a strain-free condition and the electrodes can be of flimsy construction, often permitting machining by a trepanning action when only a fraction of the material removed is actually eroded. The tool can cut also in a direction tranverse to its axis, enabling it to mill as well as drill.

These advantages show up best when cutting tungsten carbide and similar materials when the machining procedure can often be greatly simplified and machining costs reduced considerably, specially when the alternative process is diamond wheel grind-

ing. Spark erosion has found its greatest application in this field, and it is likely to be extended further with the availability of machines of increased cutting speeds and smaller cost. It would appear that there is every incentive to develop machines with a useful cutting power greater than 10kW, though for general-purpose machines a slightly smaller power may be more suitable.

It is still questionable whether spark erosion can be made to compete with orthodox methods in machining hard materials like "Nimonic" or some of the stainless steels. It is almost impossible to generalise on comparative machining costs, since individual circumstances differ so widely, but it would appear that the cost of machining by spark erosion at 10kW is made up of the following items, in descending order :—Cost of electrodes, machine depreciation and electrical power cost, provided the machine is kept well employed. Power cost is almost negligible ; labour and overheads would normally exceed all other costs. Spark erosion is likely to find increased application in this field with increase in cutting speed, especially in those cases where its other special advantages can be utilised, in particular the use of a trepanning technique or bandsaw cutting to give a gross removal rate much in excess of the erosion rate.

ACKNOWLEDGMENTS

The author is indebted to Mr. L. J. Davies, director of research, B.T.H. Company, Ltd., Rugby, for permission to publish this article, and to Messrs. N. Milne and H. C. Burford for assistance in testing and constructing the prototype machine.

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Railway Engineering Prospects

No. I

The proposals contained in the plan for modernisation and re-equipment of British Railways open a prospect of vast engineering activity during the next fifteen or twenty years. In this article, and a succeeding one, some engineering implications of the plan are discussed in the light of earlier experience both in this country and abroad

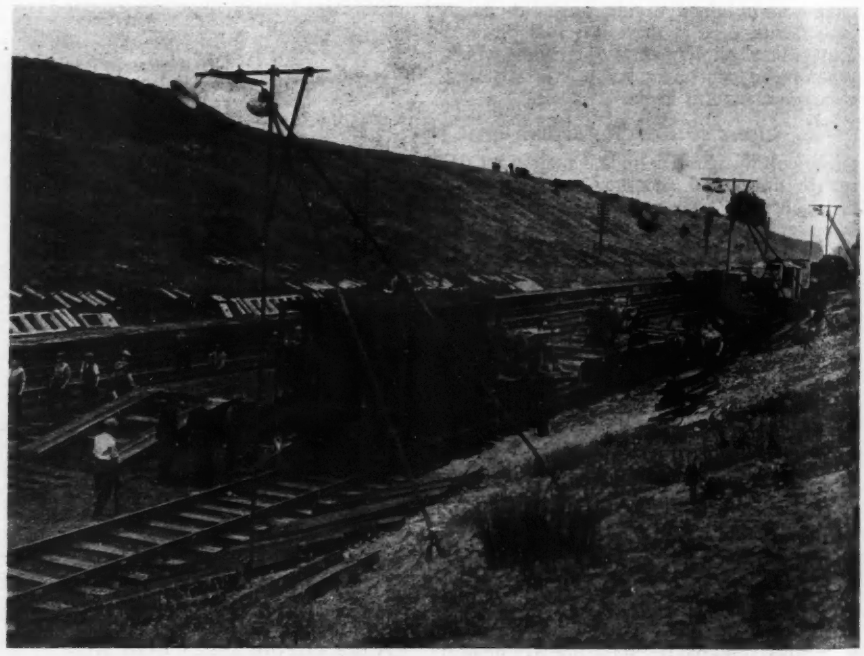
NOT since the pioneer days of railway construction in this country, when work on the London and Birmingham, the Great Western, the Southampton, the Grand Junction, and others, was under way simultaneously has such activity been visualised as that contained in the British Transport Commission plan. A first reaction, with an engineering industry already extended in many major spheres to a greater degree than ever before in its history, is undoubtedly of astonishment at the magnitude of the projected works, and the speed at which completion is forecast. The challenge to industry is indeed colossal, and one that will need the keenest of organisation to meet ; but in the meantime some engineering features that may be inferred from the broad outlines given in the plan are worth examination in some detail.

WAY AND WORKS

Speed of travel, both for passengers and freight, is the keynote of the plan, with track capable of sustaining speeds of at least 100 m.p.h., where conditions permit. This will demand a standard of maintenance and a quality of roadbed far in advance of those prevailing to-day, except on a relatively few stretches of line. Furthermore, there have been, in recent years, increasing evidences of the ageing not only of structures, but of embankments, cuttings and other works, and extensive drainage schemes have had to be undertaken. In certain bad cases stretches of line have had to be closed altogether for weeks on end to allow the civil engineers absolute possession. The gradual working up to the surface of clay has in some instances necessitated removing the formation altogether and putting in new material. Such works are not only expensive in themselves but involve delays to all traffic over a long period, while rehabilitation work is in progress.

Where the formation is sound the track itself requires fettling up to the highest standards for high-speed running. It is no more than natural that fast trains have a disturbing influence, and the restoration of pre-war schedules on certain routes has necessitated somewhat exceptional measures to render the track adequate to the demands made upon it. The future task of railway civil engineers promises to be a severe one. Contrary to general belief, diesel-electric and electric locomotives have a punishing effect, and experience in America when diesel-electric locomotives were being first introduced on a considerable scale included an outbreak of failures of the rail web section, which were confined to territories in which diesel-electric locomotives were operating. This was attributed to the low centre of gravity which increased the severity of any lateral oscillation of the locomotive in its effect upon the track. While this may be countered by the use of heavier rail sections the susceptibility of diesel-electric locomotives to slipping is causing serious maintenance problems to-day on the permanent way of American railways. Damage to the rail-head, even to the extent of burning, is not infrequent from this cause. The B.T.C. plan envisages a rise in costs of track maintenance, and even with the fullest mechanisation of the work of the gangs along the line a considerable increase in the labour force may be necessary to sustain the new standards. The keen vigilance of gangers and permanent way inspectors will be necessary in watching for unfamiliar defects and failures on lines turning over from steam to large-scale diesel-electric haulage, and in this respect the past experience of Southern men in coping with the fast electric service from London to the South Coast may be of assistance.

Permanent speed restrictions, due to curves, complicated junctions, and other physical characteristics of the routes not only slow down services and increase fuel consumption, but they constitute bottlenecks in the working of traffic. In the case of a group of trains running at close headway the existence of a speed restriction can cause reaction from one train to another until the last of a group may be delayed to a far greater extent than that accounted for by the restriction itself. In the past there have been isolated cases where realignment, or diversions have eliminated such hindrances. The Great Western had two 30 m.p.h. restrictions in rapid succession on its West of England main line, at Westbury and Frome. With heavy trains these two together cost some 3 to 4 min in running and about an extra ton of coal a day, taking all the non-stopping trains into consideration. In the "thirties" by-pass lines were constructed avoiding both stations. Improvements of this kind are foreshadowed in the plan, together with the use of two-level chairs in junction layouts,



Renewal of formation in a cutting 110 years old ; arrival of work train with bulldozers and drag-line excavators to carry out a highly organised job

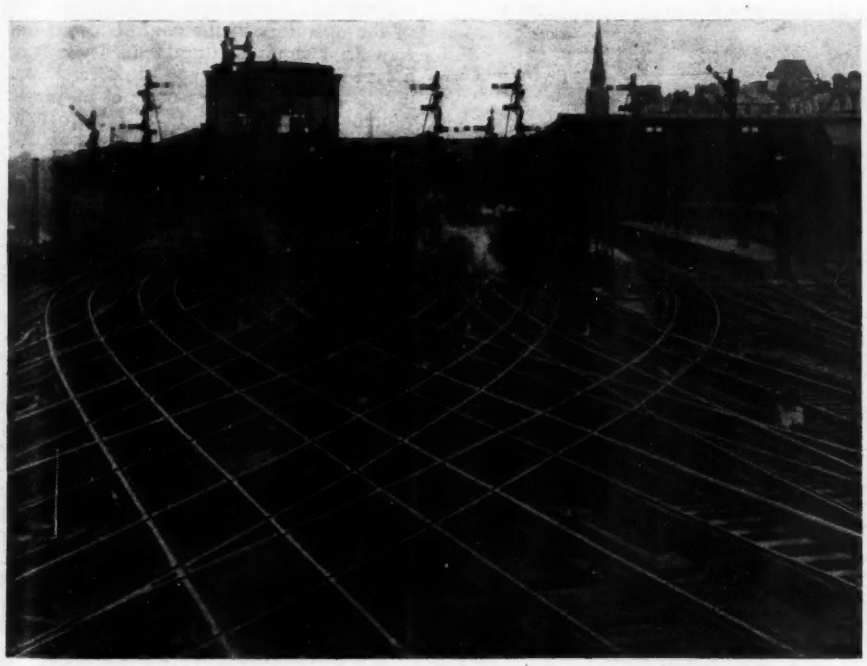
permitting the easing of restrictions, as was done at Trent Valley Junction, Stafford, from 40 to 55 m.p.h., by a scheme completed just before the outbreak of war. If speeds of 100 m.p.h. are to be achieved over extended lengths of the line realignment may be necessary on curves, even to the extent of slewing the general line of the railway and purchase of the adjoining land.

It is not only on the open road that track realignments can profitably be made. At many large centres of traffic the layout is largely traditional, as built up gradually over a great number of years. In Germany before the war much progress was made in making the approaches to stations as straight and direct as possible, while in this country one was never more conscious of the unnecessarily tortuous approach to Crewe than on that hair-raising Press run with the "Coronation Scot" in 1937, when the train had to pass through three crossover roads in succession, and in decelerating from its maximum speed of 114 m.p.h. took the first one at about 57 !

The elimination of the crossing of conflicting routes is an important matter at intensively used junctions. The outer approaches to Euston provide an interesting example. Prior to 1913 all crossings in the complicated series of junctions at Chalk Farm were made on the level, and those crossings intersecting the up main line in particular had the effect of placing a limit upon line capacity. With electrification of the Watford lines in prospect the London and North-Western Railway embarked upon the construction of a complete system of flying and burrowing junctions to eliminate entirely all conflicting routes. Under the new arrangement passenger, freight and empty stock trains traversing the system of junctions do not, at any point, cross an opposing flow of traffic. It will be appreciated that the civil engineering works involved were heavy, as there are six running lines between Willesden and Chalk Farm, and as the work was carried out stage by stage without any interruption of traffic. It was completed in 1922. The organisation of this work was a masterly feat devised and directed by Mr. E. F. C. Trench, the last Chief Engineer of the L. and N.W.R., and the first Chief Engineer of the L.M.S. Still living, at the age of eighty-six years, Mr. Trench is one of the most distinguished veterans of the engineering profession to-day.

Control panel with route relay interlocking at Northallerton, controlling 16 miles of main line ; a good example of a simple concentration of control

Such works as the Chalk Farm junctions contribute notably to the avoidance of delays at junctions. An equally effective group is to be seen in the complex triangle on the Southern Region lying just to the north of Croydon, and single flying junctions that assist in the running of fast main line traffic are to be seen at Cogload, near Taunton ; at Worting, where the West of England and Bournemouth lines of the Southern converge near Basingstoke, and at the junction of the Liverpool line with the main route from Euston to the north, at the River Weaver. Provision of many more improvements of this kind, foreshadowed in the British Transport Commission plan, cannot fail to improve train running at many key points. The engineering work involved is likely to be heavy ; indeed, there are certain "black spots" where engineering difficulties inherent in the particular location preclude the use of flying junctions at all. Borough Market, between London Bridge and Cannon Street, Southern Region, is one of the most heavily worked junctions to be found anywhere on British Railways ; yet the closely restricted nature of the site would seem to rule out altogether any prospect of giving some traffic relief by the provision of flying junctions.



A difficult junction layout in a confined space ; the east crossings outside Newcastle Central

Signalling Works

While permanent way is the basis of all railway working the running of such high-speed trains as are envisaged in the plan requires the best possible signalling arrangements to give adequate warning to enginemen when caution is needed, but no less to ensure a clear path. It has been very frequently pointed out that signal checks constitute the most serious source of delay to express trains of the present time, and those delays are minimised where control is concentrated in a relatively few signalboxes, and the signalmen themselves have a broad picture of train movements. At one time there was disinclination, in some quarters, to concentrate the control of a large area into a single box. Quite apart from any strategic considerations it was felt unwise to put all one's signalling "eggs" into one basket. But experience with the huge installation at York has largely dispelled any such apprehensions, and the remarkable improvements in operation that have resulted from that work have clearly suggested a line of policy for the future.

The estimates for the proposed new signalling works are very large ; but the work crying out to be done is vast, even by present standards of express running. Oil-lighted semaphore signals are already becoming an anachronism in this present age, and their replacement by colour-lights is overdue on all except minor and slow-running routes. But in general it would seem that the changeover to power signalling is likely to follow generally on established lines, with an increase in the number of concentrations of control, with the open stretches of line between the large centres of traffic including

much purely automatic signalling. While the scale of the new works promises to be very large, there can be little in the way of standardisation due to the great variations in layout and traffic characteristics on the different lines.

For many years past it has seemed to students of signalling practice that the long stretches of single line in Scotland gave a great opportunity to exploit the advantages of the coded remote control system of operation known as centralised traffic control, or C.T.C. The Highland line northward from Perth, the Callander and Oban, and the lines converging from north and east upon Stranraer, are, at times, far from ideal to operate on ordinary manual block principles combined with use of the electric tablet. Mention of forthcoming C.T.C. installations in the British Transport Commission plan inevitably directs attention to these lines, and to the advantages to be derived from C.T.C. working. The economies in working to be realised are not, however, so great as those on some American lines of immense length running through sparsely populated, or desert country. In Scotland the passing loops are mostly at stations, and hitherto the boxes have been manned by men who include other duties in their daily round. The complete elimination of staff at these passing places is therefore not possible. It is in the improvement of traffic regulation that the advantages of C.T.C. mostly lie.

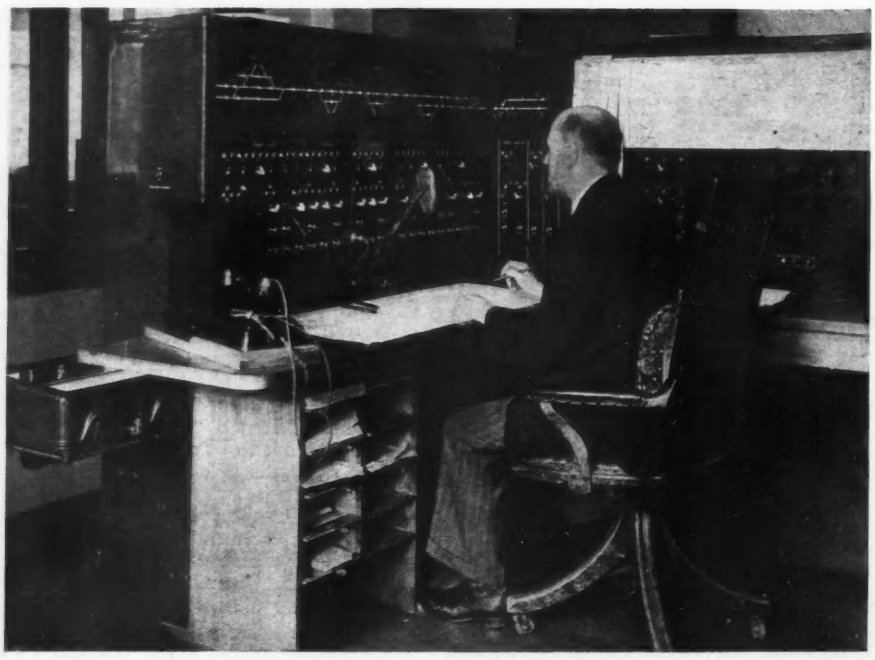
Nowadays there are no technical difficulties in the way of controlling the two long single lines through Galloway from a central control point at Stranraer. The difficulties of operation on these two lines—from Girvan, on the one hand, and Castle Douglas, on the other—give rise to a constantly changing traffic situation at times of heavy traffic. The varying performance of locomotives over long and severe gradients, and the need for inserting stock workings for balancing purposes often makes it desirable to change the scheduled crossing places of opposing trains, and while such improvisations are apt to be cumbersome to organise with no more than box-to-box telephones, and communication with a somewhat remote Control, a traffic regulator with a C.T.C. machine, and an up-to-the-minute picture of the traffic situation can take immediate decisions and implement them solely by signal indication to the trains concerned. Again, however, provision of C.T.C. in these remote districts means continuous track circuiting, and a newly-built organisation for maintenance of the electrical apparatus concerned. The intangible assets in operation have to be set against the possible cash debit of increased maintenance costs.

Marshalling yard at Toton ; extensive civil engineering and mechanised control of wagon marshalling

Marshalling Yards

Improvements of the flow of traffic along the lines, and the increased freight train speeds made possible by fitting all wagons with continuous automatic brakes must be matched by the modernisation of marshalling yards. Already in certain wide areas, and notably in Scotland, great strides have been made towards the rational integration of former facilities and freight train routes, so as to forward traffic by the most direct means, irrespective of earlier traditions. A great extension of this policy is forecast in the plan, and no fewer than fifty-five marshalling yards are scheduled for modernisation, if parliamentary authority is forthcoming. On the British railways so far capital has not been forthcoming for any save a few schemes of this kind ; but those equipped, and particularly the very few that have been fully mechanised, have between them provided a wealth of experience in design and operation that should enable the present vast programme to be set in motion without a great deal more in the way of experimenting. Well tried systems of automatic point setting and wagon retardation are in operation both in this country and abroad, and in recent years some trials have been made in the U.S.A. with systems of speed control.

Circumstances may justify this interesting refinement of control in many yards in this country. It has already been adopted in the latest one to be authorised at Thornton, Fife, referred to in THE ENGINEER for January 28, 1955. Hitherto the speed of wagons after passing through the retarders has depended entirely upon the judgment and experience of the operators in the control towers concerned. There is a natural tendency to brake a very free-running wagon too severely, and not to apply enough to one not apparently running so well. The result is locomotive time pushing down roads in the one case, and heavy impacts, with possible damage to merchandise in the other. With speed control through the retarders the disadvantages of one kind or the other are likely to be lessened. The factors involved in the equipment of new marshalling yards are not confined to the technical problems of wagon running or point operation. Every new yard to be fully mechanised presents a civil engineering task of the first magnitude—in constructing the hump and the sidings, providing foundations for the retarders, and where modernisation of an old yard is concerned, a carefully worked out "stage" programme whereby traffic can be kept moving during the changeover. What this involved in one fairly recent instance can be seen at Toton southbound yard, the construction of which was described in THE ENGINEER for June 6th and 13th 1952. The proposed equipment of some fifty-five yards within a period of fifteen years, concurrently with other civil engineering works included in the programme, is certainly a stupendous undertaking.



Control machine for single line working in New Zealand

Automatic Indexing Machine for Measuring Gear Tooth Pitch Errors

By C. TIMMS, M.Eng., M.I.Mech.E., M.I.Prod.E., and C. A. SCOLES

The need for some form of automatic circular indexing mechanism, capable of dealing with angular increments of any value, such as that of a thirty-nine tooth gear, has long been recognised at the Mechanical Engineering Research Laboratory, and this paper describes the successful outcome of development work carried out in this field at East Kilbride. The automatic equipment in question has been developed from the manually operated sine-arm type of hob and gear measuring machine originated some thirty years ago at the National Physical Laboratory by the late Dr. G. A. Tomlinson. A description of this machine is given, so that its subsequent conversion to fully automatic action can be appreciated more easily.*

THE measurement of the adjacent and cumulative spacing errors of gear wheels and pinions may be determined by comparing the pitches of the individual teeth or by direct measurement using some form of indexing mechanism. With the former, the method basically consists in measuring the departures in circular pitch of the adjacent teeth relative to the pitch of one tooth which is selected as a datum. The main weakness of this system of measurement obviously lies in the summation process involved in arriving at the final results and a high degree of accuracy must be attained for each individual pitch measurement. Alternatively in order to measure directly the spacing of the teeth in relation to their nominal angular position, means must be provided for rotating the gear accurately through angular intervals of $360/T$, where T is the number of teeth in the gear wheel. Whether this angular indexing has been obtained by means of a circular scale viewed with a microscope, a precision worm and worm wheel or some other mechanism, it has always implied a tedious and prolonged task for one or more operators, in which a precise angular setting for each tooth of the gear is required. As the pitch angles of most gears are not simple integers, it will be appreciated that successive angular settings have also involved no small amount of precalculation or reference to gearing data sheets in order to determine the successive multiples of the pitch angle, i.e. a thirty-nine-tooth gear has a pitch angle of 9 deg. 13 min, 50·77 sec. Each of the above methods of approach is a slow and exacting procedure, involving manual operation of the measuring equipment which may affect the accuracy of measurement due to operator fatigue. This is particularly the case when measuring precision gears with more than 100 teeth, as the time for the complete inspection can amount to several hours.

Tomlinson Hob and Gear Measuring Machine

A photograph of the arrangement and set-up of the equipment on a surface table is illustrated in Fig. 1. The gear wheel to be tested is mounted on a precision mandrel between the centres, and clamped to the live headstock centre, which, in turn, is integral with the large spoked wheel. Mounted freely on the common axis of rotation is a large arm, 14in in length to its terminal indicator stylus, which can be locked to the wheel by means of two knurled clamping screws. The wheel can also be locked by means of the third clamp fitted to the surface table itself. As will be seen from Fig. 3, this arrangement forms a simple sine-arm mechanism in which the rotation is effected by movement of the sine-arm, of length L, through an angle θ controlled by the difference in height of the two piles of slip gauges, represented by the expression $L \sin \theta$.

The position errors of the tooth flanks relative to the nominal angular rotation θ are measured

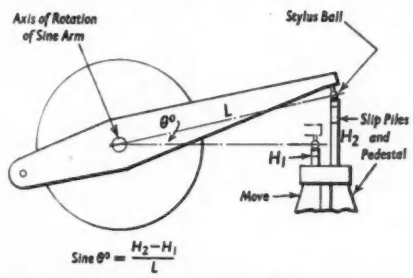


Fig. 3—Principle of sine-arm in Tomlinson machine

directly by means of the mechanical indicator shown in Fig. 1 near the gear under test. The indicator consists of a light lever suspended by a flexible steel strip hinge. The short arm terminates in a ball-ended stylus arranged to contact the flank of the gear tooth and a bevelled steel sector is fixed at the end of the long arm.

The measurements are effected by bringing the stylus into contact with the tooth flank and recording the position of the bevelled sector by means of a micrometer attached to the indicator frame. The approach of the micrometer face towards the sector is observed through a reflecting prism against an illuminated background. With this system it is possible to measure accurately an error in tooth pitch of 0·00002in. The lever arm can be readily retracted from the tooth space before the gear is rotated through the next nominal pitch movement.

It will be appreciated that testing a gear by these means, although accurate, is a long and tedious business, and even when the experimental work is completed, there remains the task of converting a long list of readings into the final form of graphical curves of cumulative and adjacent pitch errors. For each tooth measured, a sequence of some twelve operations

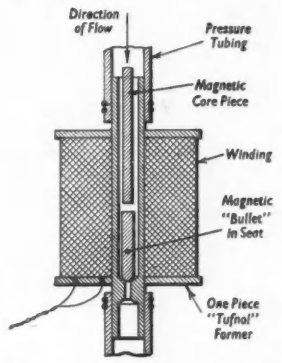


Fig. 4—Solenoid operated air-switch

is carried out, none of which need involve human participation. The two slip piles provide all the information the machine needs ; repetition only remains. The Tomlinson machine, therefore, provides an excellent basis for the development of a fully automatic gear pitch measuring machine, and such a machine is now described in the following paragraphs.

Automatic Pitch Testing Machine

Fig. 2 illustrates the modified machine as it is to-day. It is largely a pneumatically operated mechanism, and can be left to operate entirely without the presence of an observer, once the gear has been set up in the machine. At the end of the test, the machine automatically switches itself off, and sounds an alarm to tell the observer that its task is completed. The measurements it carries out are recorded on electrically-marking chart paper in the form of short Morse-type dashes. It is only necessary then to join up these marks with a pencil to form the normal cumulative pitch error curve ; the rectilinear chart paper ruling forming a convenient graph-paper background.

Pneumatic and Electrical Circuits

Fig. 5 shows diagrammatically the means employed to convert the machine to automatic operation. The pneumatically powered motion of the various elements is obtained from small air cylinders. A supply of compressed air is

* National Physical Laboratory Annual Reports, 1922 and 1925 ; Metrology Department ; Hob and Gear Measuring Machine.

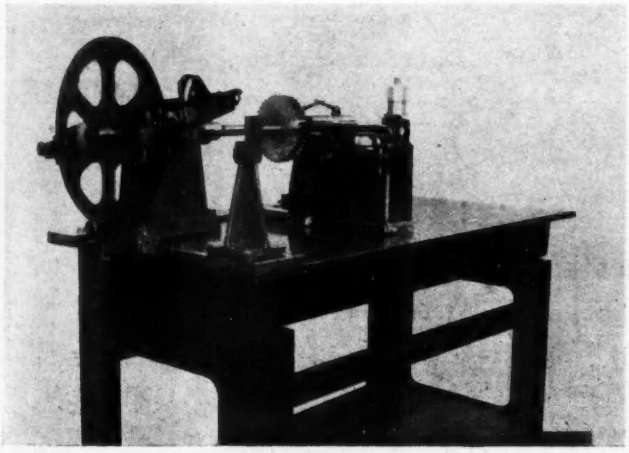


Fig. 1—Original Tomlinson hob and gear measuring machine

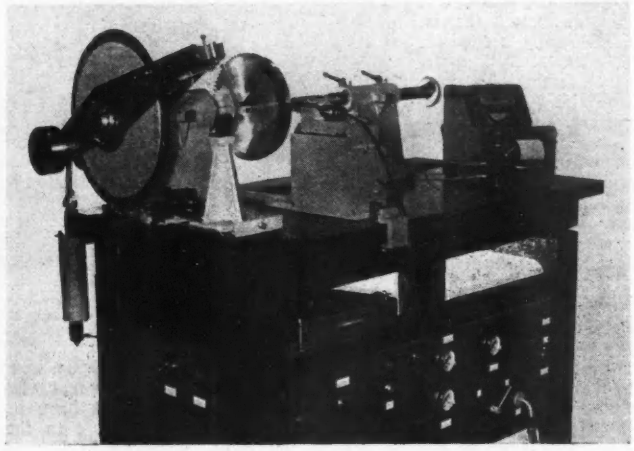


Fig. 2—Fully automatic version of the indexing machine

fed to a main pressure regulator via a hand-operated air switch and solenoid air switch. From the main regulator, the supply divides. One air line is further regulated to a pressure of 30 lb per square inch and the other to a pressure of 12 lb per square inch. From the two air tank reservoirs, connections are made to a battery of miniature roller and lever operated three-port air valves, and thence to the individual cylinders controlling the actions of the machine. The air valves are operated by a series of cams mounted on a shaft rotated by a geared-down fractional-horsepower electric motor, providing a shaft speed of 3 r.p.m. The air valves and camshaft are built into a compact unit which is driven remotely by the motor via a flexible coupling. Two extra cams on the shaft are used to operate electrical micro switches which are in circuit with the chart recorder. The purposes for which these are provided are described later.

The electrical circuit is quite straightforward; the red panel lamp indicates when the mains are switched on and the white panel lamp indicates when the motor is switched on. The green lamp serves a double purpose, for indicating that the counter wheel is not at zero, and as a current controller for the solenoid air switch.

Solenoid Air Switch

A sectional view of the solenoid air switch of this unit is shown in Fig. 4, in which the body is constructed from Tufnol material. When the electricity supply to the coil is switched off, the steel "bullet," aided by gravity and the air pressure above it, seals the restriction and hence cuts off the flow of air. When the coil current is switched on, however, the "bullet" is attracted magnetically towards the core-piece at the centre of the electromagnet, and air will then flow. As in all devices of this kind, a higher coil current is initially required to lift the "bullet" against the static air pressure above it than is subsequently needed to hold the "bullet" clear of its seating. To provide this variation in current, a tungsten filament lamp is connected in series with the solenoid. The resistance of such a lamp when cold on first switching on is considerably less than the normal resistance of the filament when hot. The lamp, therefore, automatically provides the initial solenoid current boost and also the subsequent low current control. By this means, also, the solenoid is prevented from over-heating during prolonged use of the machine. The majority of this ancillary equipment is housed behind the front panel of the machine on a shelf built under the surface plate, and is illustrated in Fig. 6.

Headstock and Double Sine-Arm

The main spindle is carried on two extra-precision angular contact ball bearings located at the ends of the headstock casting. The double sine-arm is mounted on the rearward extension of the spindle by means of two deep-groove type extra-precision journal ball bearings having no play between balls and races. The sine-arm length from the axis of rotation to the stylus ball is about 14in. A weight is attached to the rear of the arms, sufficient to raise the stylus end of the sine-arm when the air supply to the actuating cylinder has been cut off. The air cylinder, shown in Fig. 2, is mounted vertically below the rear end of the sine-arms and is coupled to them via a pivoted connecting link. Air pressure to the cylinder thus causes the sine-arms to descend until contact with the slip pile is made. The stroke speed of the piston is regulated by means of an air bleeder connected to the exhaust end of the cylinder. In addition, the spring cushion shown in Fig. 7 provides a final restraint to the downward movement of the rigid stylus ball, and thus enables a very gentle touch-down to be achieved.

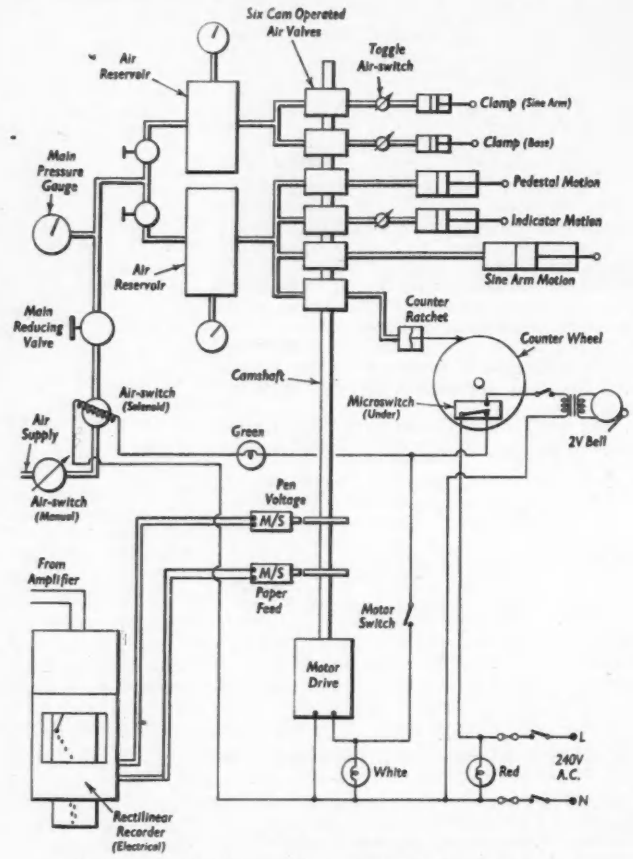


Fig. 5—Schematic diagram of pneumatic and electric systems

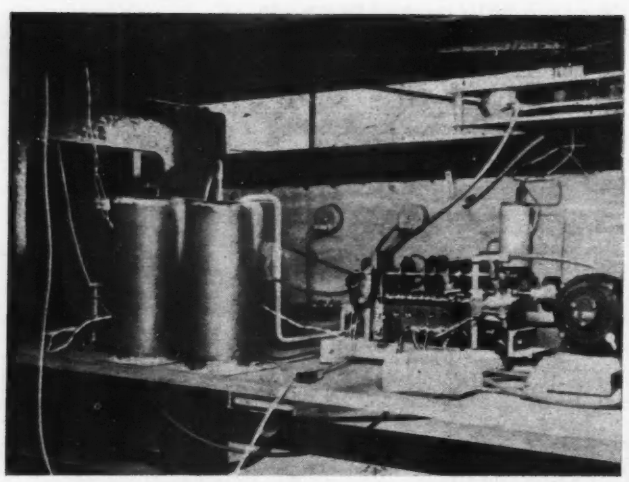


Fig. 6—Controlling mechanism of automatic gear testing machine

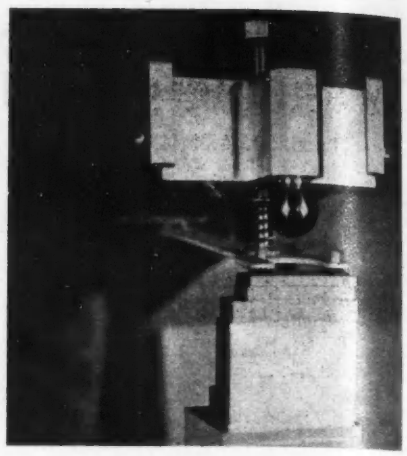


Fig. 7—Stylus cushioning pad

The reason for having two sine-arms coupled rigidly together is a kinematic one. It provides a symmetrical arrangement of the sine-arm assembly relative to the disc and reduces the possibility of slight twisting which has been observed in the single design of sine-arm, due to friction in the main bearing.

Air-Operated Clamps

There are two air-operated clamps, one of which is mounted between the sine-arms and serves to lock the unit solidly to the wheel. The other, illustrated in Fig. 8, is fixed to the edge of the surface plate in order to grip the wheel and prevent it from turning during periods of free travel of the sine-arms. Air pressure, supplied to the piston of 1¼in diameter, causes the roller mounted transversely on the end of the piston rod to wedge itself between the steel pads, and so grip the wheel against a small insert of brake lining material. A compression spring fitted to the piston rod serves to release the clamp when the air pressure is switched off. The effectiveness of these clamps is such that an air pressure of 30 lb per square inch applied to the piston will render the wheel immovable against all manual efforts to turn it. The two clamps can be isolated from their sequence control by means of the two toggle-operated air switches to be seen on the end panel of the surface table (Fig. 2). This is necessary when setting up the gear initially.

Sliding Pedestal

The side-to-side movement of the sliding pedestal unit is achieved by means of a small,

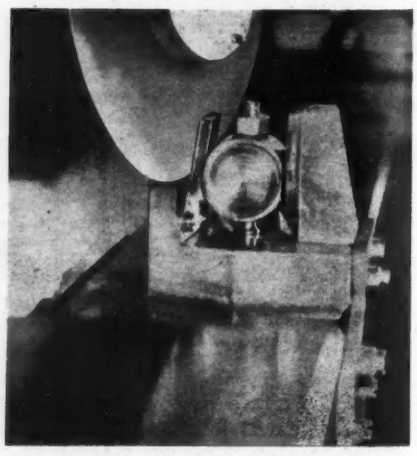


Fig. 8—Air-operated wheel clamp

short-stroke, air cylinder, shown in Fig. 2. Once again, a spring return is used, and the stroke can be adjusted for length, and also speed, by means of a small air-bleed unit.

Pitch Indicator and Recorder

At present a Taylor, Taylor and Hobson miniature gauging head and rectilinear recorder are used, as shown in Fig. 2. The head is of the side-acting type with a stylus contact pressure of less than 1 oz. This unit is mounted in a vee cradle and strapped into position by means of a padded cross bar. A small air cylinder contained inside the main base block powers

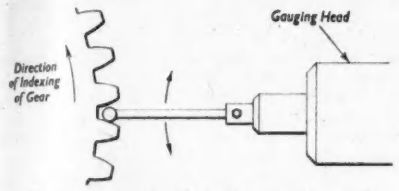


Fig. 9—Stylus contact at pitch circle of gear

the movement of the cradle via a pivoted, fork-ended lever, and a tension spring provides the return motion. In use, the cradle is gently propelled forwards against a definite but cushioned end-stop, which is preadjusted to bring the gauge head stylus into pitch-line contact with the gear tooth flank (Fig. 9). As the normal chart paper feed speed of the recorder is about 12in per minute, it was necessary to provide an additional set of cams to switch off the paper feed except for the brief period when the gauge head is in operation. In this way a Morse dash type of record was achieved and the recorder thus plotted, in effect, the pitch error curve points automatically. The magnification of the gauge head, amplifier and recorder can be varied by stages from 100 to 5000 by simply setting a control knob, so that gears of different grades of accuracy can be examined.

Cut-Out Mechanism

The essential details of the cut-out mechanism are shown in Fig. 11 and its main function is to stop the machine after the completion of each test. It consists of a toothed counter wheel which is preset to the number of teeth in the test gear and for each measuring cycle the counter wheel advances by one tooth towards its zero mark. When zero position is reached, the micro-switch operates and the motor drive and solenoid air switches are opened and a bell rings, indicating that the test is completed.

Machine Performance and Accuracy

A typical record of a seventy-two-teeth spur gear having a very noticeable adjacent pitch error is illustrated in Fig. 10. The straight line joining the ultimate marks on the record is the datum of the curve, and is obtained by recording tooth No. 1 of the gear at the beginning and end of the test. The slight slope of this datum is due to the fact that the slip pile can only be set to the nearest 0·0001in, and in nearly all cases a residual of a few hundred-thousandths of an inch per setting occurs, which shows as a slight obliquity of the record. Final provision of the straight line datum, however, automatically puts this right, and the individual tooth errors can be observed at a glance. The complete record refers, of course, to one set of flanks of the gear ; at present it is necessary to carry out a second test to measure the other set of flanks. It is intended, however, to modify the gauge head unit to measure the upper and lower tooth flanks at each tooth setting, and to provide a chart bearing a double record.

An important advantage of the automatic version of the Tomlinson machine is that the human factor is not involved, therefore eliminating observational errors, setting errors, and thermal errors due to prolonged handling of the sine-arm, &c. The use of a pneumatic setting of the sine-arm ensures constancy of stylus pressure on the slip piles, and thus errors due to varying compression of the ball are avoided. The repetitional accuracy of the machine was tested by making a series of measurements on a single tooth of the gear (to do this it was only necessary to arrest the slip pile pedestal movement), repeated at many positions round the gear and the repetitive accuracy per cycle is of the order of 0·000005in. The overall repeatability of results is indicated by the repeat records shown in Fig. 10.

Future Design

The present automatic instrument has been developed directly from an existing Tomlinson machine and the results of this work have provided much experience and the knowledge that accurate gear pitch measurement can be achieved automatically. Consideration is now being given to the most suitable form which a machine, designed from first principles, should take. Primarily, it is considered that the horizontal axes and mandrel should be replaced by a vertical axis machine having a rotating work table upon which the gear can be mounted concentrically, thus avoiding the need for a large stock of precision mandrels of various diameters, and overcoming any errors due to bending of such

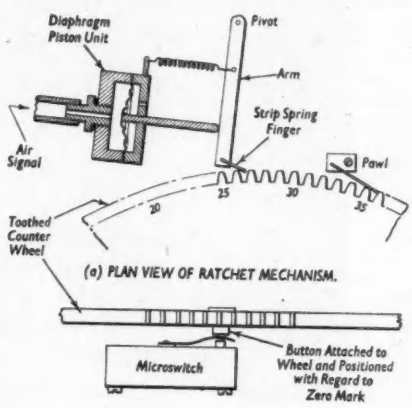


Fig. 11—Details of cut-out mechanism

mandrels when heavy gears are mounted on the machine. The necessary low friction support of such a table will probably be achieved by radial and thrust type air-bearings. Preliminary experiments in this direction have shown that very precise rotational accuracy can be achieved quite simply by these means, and with very low frictional torque. The sine-arm, mounted beneath the table, would then oscillate in a horizontal plane, and instead of slip gauge piles adjustable end-bars would be used, limiting the sine-arm swing in both directions. The pitch and also concentricity measuring heads would be mounted on the underside of a rigid but adjustable bridge straddling the circular table, and it is possible that the former head will consist of a pair of slit-shaped air jets measuring both flanks of a tooth simultaneously, and providing twin records on a double-pen pneumatic recorder.

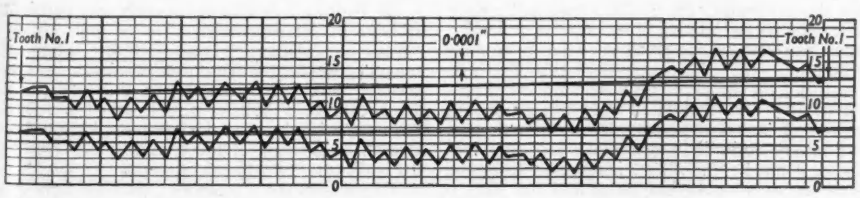


Fig. 10—A typical record of the pitch errors of a 72-tooth gear together with a repeat record

Acknowledgments

The work described was carried out in the Mechanisms and Metrology Division of the Mechanical Engineering Research Laboratory as part of the research programme of the Mechanical Engineering Research Board. It is published by permission of the Director of the Laboratory.

Smoke Plumes from Chimneys

At the Institution of Mechanical Engineers, last Friday, February 11th, a paper on " Effects of Velocity and Temperature of Discharge on the Shape of Smoke Plumes from a Funnel or Chimney : Experiments in a Wind Tunnel," was read by L. W. Bryant, B.Sc., and C. F. Cowdrey, B.Sc. The work was carried out at the National Physical Laboratory. We print here the " Introduction " and certain conclusions.

There is not much experimental evidence relating to the behaviour of a jet or smoke plume in the neighbourhood of the chimney or funnel from which it is discharged. In particular, the effects of velocity and temperature of discharge on the initial course of the jet when it issues into a current of air are known only very roughly. In the course of a number of investigations on smoke plumes from ships' funnels and from power station and factory chimneys, it became clear that some study of the case of a simple jet discharged at right angles to a uniform wind current was necessary to an understanding of practical problems of smoke discharge, including especially the effects of buoyancy in the case of a heated jet. A preliminary study of this kind was made in a wind tunnel at the N.P.L. during 1948, and an attempt was made to correlate all the experimental results in such a way that extrapolation to greater distances from the stack would be possible. The formulæ then devised have now been modified in the light of further experience and some few additional tests. A method of computing the course of the plume, given the temperature and velocity of discharge and the wind speed, is suggested, starting where model data stop and proceeding to regions where the dimensions of the chimney no longer influence the spread of the smoke. In these regions the path of the smoke depends primarily on atmospheric conditions and on the height of the chimney, and use can be made of the work of Sutton (1947).* The need for *ad hoc* experiments to deal with special cases of ships' structures and built-up areas is likely to remain, but such experiments can be undertaken and interpreted intelligently only if the underlying principles of the problems are systematically studied.

No very great precision can be claimed for the experiments owing to the very low wind speeds which were inevitable when effects of heating on small-scale models were being studied. The effect of buoyancy, for a given ratio of speed of efflux to speed of wind, should be approximately proportional directly to linear dimensions (say, to the diameter of the chimney stack exit), also proportional to the difference of temperature between exit gas and the surrounding air, and proportional inversely to the square of the wind speed. There is little or no possibility of conducting model tests at temperatures much higher than those of the corresponding full-scale conditions, so that if the scale must be small, the velocities of test must be very small. To represent a 30ft per second jet (say, 10m per second) with a model to a scale of 1/100, a jet of 3ft per second (1m per second, say) would be required to reproduce the pattern of smoke plume for a given temperature difference at the exit. It is very difficult to be sure of a uniform tunnel wind stream at such a low speed as 3ft per second, and difficult to measure it with sufficient accuracy. Nevertheless, it is believed that the data obtained in the N.P.L. open jet tunnel show sufficient consistency to provide valuable basic information.

Some notes are appended to the main report referring to the use of models and the interpretation of results from them. These notes are based

* Sutton, O.G., 1947, *Journal* Royal Meteorological Society, Vol. 73, page 426, " The Theoretical Distribution of Airborne Pollution from Factory Chimneys."

on the systematic calculations on smoke paths and on the concentration of sulphur dioxide at ground level from certain typical chimneys. The effects of chimney height and diameter, and of washing as against discharging hot gas, are discussed by means of examples worked out.

SUMMARY OF CONCLUSIONS WITH REGARD TO THE ADVANTAGES OF WASHING THE EFFLUENT

(1) The loss of buoyancy of the effluent which results from washing destroys the advantage of the reduction of sulphur dioxide content at the exit so long as the turbulence of the air is less than that corresponding to winds of speed of the order of 15 m.p.h.

(2) The advantages of washing become more pronounced as wind speed and turbulence increase. It is sufficient to consider conditions of moderate wind of speed of the order of 20 m.p.h., rather than any less speed ; so that a turbulent condition is taken as a basis in assessing the advantages of washing. Higher winds in built-up areas in Britain occur usually less than one day in sixty.

(3) With a given volume rate of discharge of the effluent gas, there is a critical diameter of exit for the stack above which the maximum concentration of sulphur dioxide is greater for the washed than for the unwashed plume. If the height of the stack is 100ft or more, this critical diameter is greater than 30ft.

(4) If the height of the stack is not less than 200ft, the greatest concentration of sulphur dioxide anywhere on the ground will not exceed 1/1000 of the concentration at the exit if the effluent is unwashed, so long as the speed of the wind is not much above 20 m.p.h.

(5) Maximum concentration occurs much nearer the stack when the effluent is washed than when unwashed. Increase in height decreases the maximum concentration and causes it to occur farther from the stack. Even when the maxima of washed and unwashed smoke are approximately equal, the concentration of sulphur over a very considerable area beyond the first ¼ mile from the stack is much greater in the latter case than in the former.

(6) When washing is decided upon, the velocity of exit of the effluent gases should be as high as possible. This can be arranged, if necessary, by reducing the diameter in nozzle fashion at the top of the stack.

(7) When it is required to consider concentrations at a level comparable with the height of the chimney, it will be found that they will be notably greater than concentrations on the ground for a stack 50ft high, and they will be very little altered by variation of stack height. In these circumstances washing is advisable, unless the site under consideration is sufficiently far, say 1 mile, from the stack.

(8) When a power station is situated in a built-up area with buildings of very uneven height, or in a countryside of a hilly nature, it is suggested that a model test is invaluable to determine the course of the smoke plumes as influenced by the contours of the surroundings.

Book of Reference

Whitaker's Almanack, 1955. London: J. Whitaker and Sons, Ltd., 13, Bedford Square, W.C.1. Price 15s. —This is the eighty-seventh annual edition of "Whitaker," and its 1190 pages are packed with information about a multitude of matters. There are many establishments—offices, works and libraries, for example—where almost daily reference to some scientific, commercial, poli.ical or social matter is required, and there must be few occasions when "Whitaker" cannot provide the answer. In this new edition, the main statistical section has been brought up to date, the Commonwealth section has been enlarged, world affairs are noted, and the regular articles, such as "Science, Discovery and Invention," provide, as usual, an interesting and accurate record of outstanding events and developments.

SMALL POWER PALLET TRUCK.—A new pedestrian-controlled battery driven pallet truck for loads of up to 3000 lb is now being made by Lans. -Bagnell, Ltd., Kingsclere Road, Basingstoke, Hants. The truck has a built-in charger and an automatic cut-out and a circuit breaker designed to trip if the truck is overloaded or the batteries discharged. It has a 6in platform lift, which enables stillages to be handled as well as pallets.

Electronic Digital Computers

No. I

In this country electronic digital computers are nearing a stage in their development at which they may be applied generally in industry and commerce, for various processes involving very rapid computations or analysis of statistical data. Because of their high cost these computers have, in practice, hitherto been available only to very large organisations. In this and subsequent articles we refer, briefly, to the activities in this field, of some British firms. The first article deals with the "402" computer, made by Elliott Brothers (London, Ltd.), a company which has recently introduced a computing service in London.

IN our issue of January 21, 1955 (page 97), we referred, briefly, to the introduction of a computing service by Elliott Brothers (London), Ltd., Century Works, Lewisham, London, S.E.13. This service is rendered with the help of the new Elliott "402" electronic digital computer which is also available as a standard commercial product. The following brief description of the computer is based on information recently received from the manufacturer.

The "402" computer is suitable for a great variety of applications in commerce, science and industry : for example, the processing of data, such as cost accounting and the analysis of statistical information ; the determination of a three-dimensional trajectory for a guided missile ; and matrix multiplication, which is required in structural engineering and in electrical network analysis. Some examples of the performance of the "402" computer on problems of this kind are given later in this article.

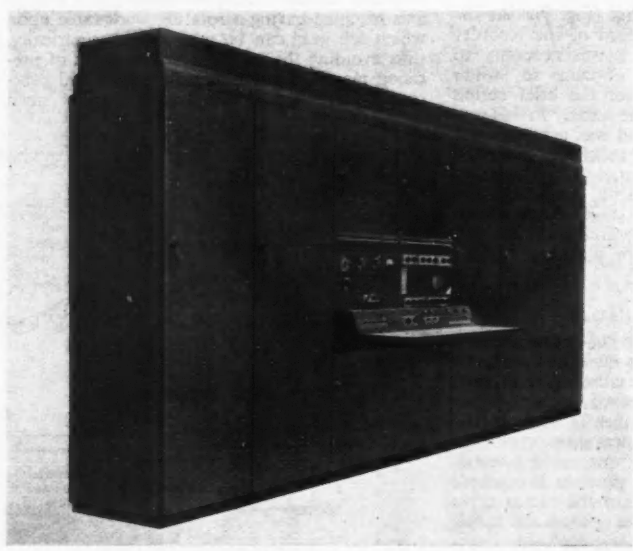


Fig. 1—Electronic digital computer in a commercial form. The Elliott "402" computer consists of seven individually ventilated cabinets with a built-in control desk

The principle of this and other digital computers can best be understood by considering the operation to be broken down into a number of stages. The first step is the preliminary one of formulating the problem mathematically and of breaking it down into a series of simple arithmetical operations involving addition, subtraction, multiplication and division. This process of expressing the problem as a series of arithmetical operations linked by a number of control instructions is known as programming. The programme is next coded into a form suitable for the computer, on five-hole punched paper tape which is fed into the computer. A one-word input can also be fed from the built-in number generator. In the computer the five-hole "words" on the paper tape are scanned photo-electrically and translated into corresponding groups of electrical pulses. The computer uses the binary scale in which there are only two digits, 0 and 1 : the digit 1 is represented by the presence of an electrical pulse and the digit 0 is represented by the absence of an electrical pulse. Each group of pulses containing thirty-two binary digits is known as a "word." In each word some of the thirty-two digits represent control instructions, while the remainder denote the value of the number (which itself represents an intermediate stage in the complete arithmetical process). Numbers equivalent to nine or ten decimal digits can be handled in this way.

To carry out any calculation the digital computer requires two main facilities : first, it must be able to store a large number of "words" (as described below) and to release them as required by the control instructions, and, secondly, it must be able to carry out the primary arithmetical processes of addition and subtraction—this it does by the use of a series of "gate" circuits for handling the pulses.

Two kinds of instructions are used in the operation of the computer: the first kind controls the sequence of arithmetical operations; the second kind are special instructions which are framed to reduce both the time needed to prepare and scan the programme and the storage space needed to handle the programme in the computer. The ordinary instructions are followed by the computer in the sequence specified by the programme. However, the incidence of one of the special instructions causes control to be directed along one of two alternative paths, the choice being determined (for example) by the sign of the particular number that is in the accumulator at the given time. In response to such a special instruction the computer can be made to obey groups of orders repeatedly until a pre-arranged criterion is reached and, thereafter, to carry out other sequences automatically.

Sub-routines, consisting of established sequences of orders, can be kept in a store readily accessible to the programme controller. For example, sub-routines could be used to derive roots and trigonometrical functions which frequently recur ; to convert decimal notation on the punched tape into binary notation in the computer, and to organise page layout in printing-out the results. By linking together a number of sub-routines the operator can reduce the time needed for preparing a programme.

The output of the computer is obtained either from an electrically operated typewriter or a paper tape-perforator and page printer.

As illustrated in Fig. 1, the computer consists, briefly, of an assembly of seven individually ventilated cabinets. These cabinets house a magnetic store stabilised power supplies, a built-in control desk, and 223 plug-in units (Fig. 2). Each cabinet is built of stove-enamelled "Duralumin" with doors at the front and back. The overall dimensions of the computer are 13ft by 2ft by 7ft.

To provide the "memory" facility there are two stores. The first consists of fifteen single-word magnetostrictive nickel delay-line registers

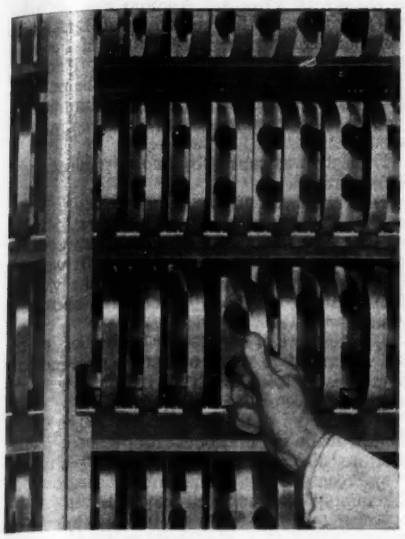


Fig. 2—The seven cabinets of the "402" computer contain racks carrying 223 standard plug-in units in which the electronic equipment is mounted

(Fig. 3) in which the pulses representing "words" are continuously circulated and are immediately accessible for computation, when required. Seven of the nickel delay-line registers in the immediate-access store provide what is known as a "B-line facility": that is, they are available for modifying the instructions previously given to the machine. To back up this immediate-access store there is a main store consisting of a magnetic drum (Fig. 4) which rotates at 4600 r.p.m. and carries twenty-three tracks, each containing 128 "words," the total capacity being 2944 "words." The average time required to obtain access to eight electronically selected tracks is 6·5 milliseconds.

For monitoring the performance of the computer there are two built-in cathode-ray-tube displays, each of which is arranged to show a selected word. Facilities for testing the plug-in units are embodied in the computer and a trolley-mounted oscilloscope is provided for general-purpose testing. Component failure may be anticipated by carrying out check programmes and, at the same time, varying (under programme control) h.t. supplies, frequency and timing.

All controls for the power supply and for operating the computer (including those for monitoring and testing and for the input tape reader) are built into the control desk (Fig. 1). The power requirements are 8kVA, 415V, three-phase, four-wire, 50 c/s. A motor alternator is supplied to serve as an alternative to the mains supply. Protective interlocks are incorporated. A keyboard perforator is supplied for punching the input tape.

The speed of the computer is specified as follows:—Digit rate, 333,000 per second; digit time, 3 microseconds; word length, 34 (=2+32) digits; word time, 102 microseconds; addition and subtraction, 204 microseconds; multiplication and division, independently of sign, 3·3 milliseconds.

Some examples of the use of the "402" computer have been given by the manufacturer.

A typical problem is that involved in the determination of electron trajectories in a cylindrical diode valve. In such a system the electrons move radially in response to two influences—a steady bias potential and a large oscillatory r.f. potential. The motion of the electrons is determined by the following equation:

$$\frac{d^2r}{dt^2}=\frac{e/m}{\log_e(r_a/r_c)}\left[\frac{V_0\sin(\omega t\times x)+V_{DC}}{r}\right],$$

where

V_0 is the peak r.f. potential.
V_{DC} is the bias potential.
r is the distance of the electron from the axis of the diode.
r_a is the anode radius.
r_c is the cathode radius.
e/m is the ratio of charge/mass of electron.
t is time.
$\omega=2\pi f$ where f is the r.f. frequency.

The problem is to use this equation to determine the motion of electrons emitted from the cathode at various points in the r.f. cycle as expressed by the phase parameter x.

After the problem has been broken down into a suitable programme the computer takes two minutes twenty seconds to calculate a typical trajectory covering twelve radio-frequency cycles. The time required to obtain the same solution on a desk calculating machine is stated to be about sixty hours. In this and other examples, it will be appreciated that the calculation times will vary widely depending upon the specific conditions of the problem. Accordingly, the values of time quoted should be regarded as being no more than representative. The three-dimensional trajectory of a guided missile for example, assuming a calculation of about eighty steps, may take about thirty minutes.

Another class of problem involves matrix multiplication: in structural engineering and electrical network analysis, for example, it is often necessary to find the product of two matrices; such a calculation for 20×20 matrices occupies three and a half minutes.

A typical example involving the solution of simultaneous equations is in mass spectrometry. Here the results of measurements give sets of linear simultaneous equations in which the matrix of coefficients on the right-hand side remains constant for many equations. The solution for any right-hand side can be obtained by inverting the matrix and by multiplying the inverse matrix by the vector on the right-hand side. Inversion of a 20×20 matrix requires twenty minutes on the "402" computer.

Another kind of application for the computer is in data reduction or data processing at high speed. In wind tunnel work, for instance, data can be recorded directly on punched tape and fed into the computer. In this way, on a typical thirty-minute run in a wind tunnel, thirty sets of six strain gauge readings and other quantities can be translated into the force and moment coefficients that are required to specify subsequent experiments, within three minutes.

The electronic computing service set up by Elliott Brothers (London), Ltd., is available, on a programming and machine time basis, for the solution design, research and kindred problems in commerce and industry. For this service, charges are separately assessed for programming and machine time. Customers who prefer to formulate their own programmes can make use of various facilities provided by the company, including the issue of the Elliott library of subroutines. The service should enable managements to assess at reasonable cost the possibilities of employing electronic computing in the solution of specific problems.

(To be continued)

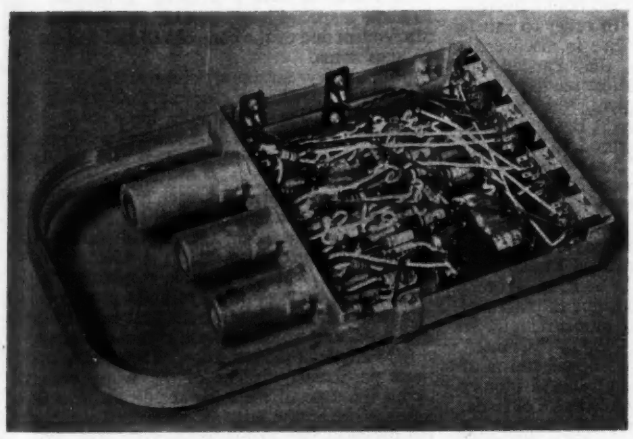


Fig. 3—One of the fifteen nickel delay-line registers in the immediate access store of the computer. Each register stores a single word of thirty-two binary digits to which access is immediate

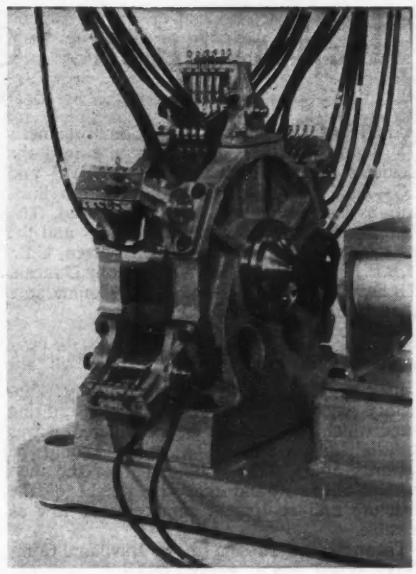


Fig. 4—The main store of the "402" computer. It is a drum which is coated with magnetic oxide and rotates at 4600 r.p.m. On each of twenty-three separate tracks it stores 128 "words" (each of thirty-two binary digits) the total capacity of the drum being 2944 words

National Inspection Council for Electrical Installation Contracting

A NATIONAL INSPECTION COUNCIL for Electrical Installation Contracting is to be set up. This decision has been announced by an organising committee composed of representatives of the Institution of Electrical Engineers, the British Electricity Authority, the Area Electricity Boards, the Electrical Contractors' Association (Inc.), the Electrical Contractors' Association of Scotland, the National Register of Electrical Installation Contractors, and the Electrical Power Engineers' Association and the Electrical Trades Union, representing the Employees National Committee of the Electricity Supply Industry.

The objects of the Council are:—

(*a*) To set up, issue, publish and maintain a roll (for Great Britain and Northern Ireland, the Channel Islands, the Isle of Man and Eire) of Approved Electrical Installation Contractors who shall have given evidence of their competency by conforming with the Rules and Regulations for the time being of the Council and undertaken the responsibility required by the conditions of enrolment.

(*b*) To grant and issue certificates whereby the public may be afforded a means of distinguishing Electrical Installation Contractors who shall have given evidence of their competency, and to cancel and withdraw the same.

(*c*) To inspect electrical installation work in Great Britain and Northern Ireland to determine whether such electrical installation work conforms with the requirements as to workmanship, safety and general standards which may be laid down.

(*d*) To encourage improved methods of protecting consumers of electricity against faulty or unsafe electrical installations and appliances, and to bring to the notice of the public matters concerned with the safety, standardisation, development and improvement of electrical installations.

Report on the "Comet" Accidents

No. I

ABSTRACTS from the Commissioner's Report* of the Court of Inquiry into the accidents to the "Comets" "G—ALYP" and "G—ALYY" which was published with illustrations last week, are here reproduced. The Commissioner was Sir Lionel Cohen and the assessors were Sir William Scott Farren, C.B., M.B.E., F.R.S., Professor William Jolly Duncan, C.B.E., D.Sc., F.R.S., and Air Commodore Allen Henry Wheeler, O.B.E.

History of "Comet" Project

In order to provide an economically satisfactory payload and range, at the high cruising speed which the turbo-jet engines offered, it was essential that the cruising height should be upwards of 35,000ft—double that of the then current airliners—and that the weight of the structure and equipment should be as low as possible.

Throughout the design [the de Havilland Company] relied upon well-established methods, essentially the same as those in general use by aircraft designers. But they were going outside the range of previous experience and they decided to make thorough tests of every part of the cabin structure. They gave special attention to the structural integrity of the pressure cabin. The difference† between the internal and external pressure (8¼ lb per square inch) was about 50 per cent greater than that in general use and there was in addition a larger difference between the internal and external temperatures.

The British Civil Airworthiness Requirements (B.C.A.R.) called for a "proof" pressure of 1⅓ P (under which the cabin must show no signs of permanent deformation), together with a "design" pressure of 2 P (at which the material may reach its ultimate strength). These requirements were the same as those of the International Civil Aviation Organisation (I.C.A.O.) and also those of this country for military transport aircraft. De Havillands used a design pressure of 2½ P and tested the cabin to 2P. Two test sections of the cabin were built. The front part, 26ft in length, extended from the nose nearly to the front spar of the wing, and included typical windows, hatches and door. The centre part, 24ft in length, extended from a few feet in front of the front spar to a few feet aft of the rear spar, covering the large cut-out containing the wing structure.

Their reasons for adopting these substantially higher figures were two. They believed, and this belief was shared by A.R.B. and other expert opinion, that a cabin which would survive undamaged a test to double its working pressure, 2 P, would not fail in service under the action of fatigue‡ due to the pressurisation to working pressure, P, on each flight, and to other fluctuating loads to which it is subjected in operations.

Secondly, they considered that it would ensure a larger margin of safety against the possible failure of windows, doors and hatches. These are contingencies which had been shown by experience to be a serious risk, for even if nothing worse happens, the resulting loss of pressure may be rapid.

So much importance did they attach to this latter consideration that they made many tests of window panes to very high pressures. In addition, they applied pressures of between P and 2 P some thirty times to the test section of the front part of the cabin together with a series of 2000 pressurisations to rather over P. These tests were not intended as a test of the fatigue-resisting properties of the structure, but rather as providing an assurance that the cabin would be satisfactory as a pressure vessel. But they undoubtedly contributed to de Havillands' confidence in the soundness of the cabin.

During the period 1949 to 1951 there had been growing among all aircraft designers and users a realisation that the life of the essential structure of an aircraft was not unlimited. The effects of atmospheric turbulence had produced unexpected and relatively early failure of the wings of certain transport aircraft. Gusts are most severe near the ground and in the Tropics. Methods had been devised, and have since been improved and extended, for determining their frequency and intensity. In the light of this knowledge, repeated loading tests of the wings of transport aircraft became accepted as necessary. Tests of the "Comet's" wing were made in close co-operation with R.A.E.

Until about the middle of 1952 the likelihood that the fatigue resistance properties of a pressure cabin demanded further precautions, either in design or by test, than were provided by the current static strength requirements had not been realised. The matter first came to de Havillands' notice through Mr. Harper's association with the problem on Service (R.A.F.) transport aircraft, as a member of the Joint Airworthiness Committee (J.A.C.) of the Ministry of Supply. Draft Requirements (Paper 579, October, 1952) called for a static test to 2 P, a proof test to 1⅓ P, together with repeated loading tests of 1⅓ P applied 10,000 times.

At about the same time A.R.B. were reviewing the civil position. In due course they issued proposals in Paper No. 230 (June 19, 1953) which called for the same static test to 2 P and proof test to 1⅓ P but raised the number of applications of 1⅓ P to 15,000. At the same time the paper suggested that certain structural parts, such as riveted joints, door and window frames, &c., might have to be designed to 3 P (on the ultimate strength of the material), in order to meet these requirements. It also stated that the figure of 15,000 was intended to cover the number of applications of P during the life of an aircraft, and that the test pressure of 1⅓ P was intended to cover the phenomenon of "scatter" in the fatigue strength of different cabins built to the same design.

The result of these developments was that in July, 1953, de Havillands reconsidered the position of the "Comet's" cabin. Up to that time no "Comet" had exceeded 2500 hours' flying—say, 800 pressurised flights. In order to satisfy themselves of its safety, and also to discover its probable safe working life, they carried out repeated loading tests of the test section of the fore part of the cabin, applying the working pressure P about 16,000 times. By September, 1953, this specimen had withstood 18,000 applications of P in addition to some thirty earlier applications of pressures between P and 2 P.

These tests were ended by a failure of the skin in fatigue at the corner of a window, originating at a small defect in the skin. But the number of pressurisations sustained was so large that, in conjunction with the numerous other tests, it was regarded as establishing the safety of the "Comet's" cabin with an ample margin.

Meanwhile, on May 2, 1953, "Comet" "G-ALYV" had crashed in a tropical storm of exceptional severity near Calcutta. An inquiry was directed by the Central Government of India. The Court reported on May 26, 1953, that the accident was caused by structural failure of the airframe during flight through a thundersquall. Fatigue failure of the cabin was not then suspected as a cause and in my opinion the evidence adduced in the course of the present Inquiry affords no sufficient reason for doubting the conclusion of the Indian Court.

Weather Conditions at the Time of the Accident

From take-off at Rome to the time of the accident at approximately 27,000ft near Elba "Comet" "G-ALYP" experienced essentially good weather conditions. In salvage operations fifteen bodies, various mail bags and some aircraft wreckage and personal effects were recovered.

An examination of the bodies recovered was carried out by Professor Antonio Fornari, who was acting under the direction of Dr. Folco Domenici, Director of the Institute of Forensic Medicine in the University of Pisa. Professor Fornari gave evidence before me and he put in a report which had been prepared by him and Dr. Domenici. The substance of their report may be summarised as follows :—

(1) Death was caused by impact against parts of the aircraft.

(2) There was serious lesions resulting from explosive decompression and deceleration.

(3) The probable point of impact between the bodies and the structure of the aircraft was the forepart of the fuselage, perhaps in the vicinity of that part of the fuselage which lies above the engines.

(4) There were burns on the bodies of all the victims, but they presented post-mortem characteristics from which the inference was that the burns took place after death.

About 70 per cent of the empty weight of the aircraft, made up of about 70 per cent of the structure, 80 per cent of the power plant and 50 per cent of the equipment, was recovered. The amount of wreckage recovered was greatly in excess of the expectations entertained in March, 1954, when the decision to allow the "Comets" to fly again was taken. A remarkable fact was the small amount of damage which had been caused to the structure either by immersion in sea water or in the process of salvage.

The Abell Committee

Immediately on receiving news of the accident B.O.A.C. had decided to suspend their normal "Comet" passenger services, for the purpose of carrying out a detailed examination of the aircraft of the "Comet" operational fleet in collaboration with A.R.B. and de Havillands. A committee under the chairmanship of Mr. C. Abell, the Deputy Operations Director (Engineering) of B.O.A.C., and composed of representatives of A.R.B., B.O.A.C. and de Havillands, was appointed to consider what modifications were necessary before B.O.A.C. could properly seek the agreement of the Minister of Transport and Civil Aviation to the resumption of passenger services by "Comet" aircraft. According to the evidence of Mr. Abell, they came to the view that possible main causes of the accident were as follows :—

(*a*) Flutter of control surfaces. It was decided to make a special inspection of the whole of the mechanism and of the control surfaces and mass-balance arms.

(*b*) Primary structural failure. They considered, in particular, the possible effects of gusts, in causing abnormally high loads, and surveyed all parts of the structure of which there was any suspicion in the light of previous experience.

(*c*) Flying controls. For each hydraulic power unit operating a control surface there is an output circuit connected to the control surface and an input circuit connected to the pilot's control in the cabin. Many possible sources of malfunctioning both of the hydraulic power units themselves and of these mechanical circuits were examined and special investigations initiated.

(*d*) Fatigue of the structure. They had in mind more particularly fatigue of the wing, because about the time of the Elba accident cracks had appeared near the edge of the wheel wells, on the under-surface of the wing of the first prototype, which was under test at R.A.E., after the equivalent of about 6700 flying hours. They re-examined also one or two other parts of the structure at which they felt fatigue effects might be appearing.

(*e*) Explosive decompression of the pressure cabin. They had no reason to suspect the primary structure of the cabin. Their main concern, however, was the window panels, where they thought it necessary to consider possible defects which might cause weakness not revealed in the tests made during design at de Havillands.

(*f*) Engine installation. Their main preoccupation here was with the possibility of fire and investigations were made at a number of points in order to remove every cause of possible fire risk which they could imagine.

(To be continued)

* Publication C.A.P. 127, Ministry of Transport and Civil Aviation. Price 8s.

† This difference is sometimes referred to hereafter as "P."

‡ For the appendices see the Report.

H.M.S. "Ark Royal"

BY OUR NAVAL CORRESPONDENT

H.M.S. "ARK ROYAL," Britain's newest heavy carrier, with a displacement of 36,800 tons, commissions for service this month—nearly twelve years after she was laid down at Cammell Laird and Co.'s yard at Birkenhead. While the value of the small escort carrier—the vessel which provides air cover for convoys in the wide oceans—is not questioned, except possibly by one or two air enthusiasts who know little about naval operations, there has been considerable controversy about the need for heavy carriers. In particular, the size of these vessels seems to bear no relation to any well-defined standard. The United States "Forrestal," launched two months ago, has a displacement of 60,000 tons; the British "Centaur" and "Albion," which joined the Fleet last year, displace no more than 20,000 tons. Finally, many will remember the good work done by the 13,000-ton "Glory" class in the Korean campaign. In spite of the great variation in their size, all these ships may be described as heavy carriers and it might be of interest, before describing the main features of the "Ark Royal," to discuss the reasons for this variation and the kind of heavy carriers likely to be built in the future.

In the early days of carriers, their flight deck had to be of sufficient length and size to fly-off and land-on aircraft and also to provide sufficient space as a parking ground for aircraft about to fly-off and after landing-on. The higher the speed of the carrier the less the difficulty in flying-off and landing-on. Thus, in the 'thirties, with only the relatively slow piston-engine aircraft available, it was found that ships of about 26,000 tons displacement and 31 knots speed were required. When the war broke out, Britain was in fact building five carriers of approximately this tonnage and speed. By then, however, the pneumatic wire purchase had been developed and it was becoming the practice to catapult aircraft instead of flying them off. With the outbreak of World War II, special efforts had to be made to build escort and anti-submarine vessels and minesweepers, but on the completion of the four "King George" class battleships the "Eagle" and "Ark Royal" were laid down to provide for the larger and heavier types of aircraft likely to be required in the future. (Two others of this class were cancelled at the end of the war.) The "Glory" class were also laid down about this time for immediate service in the Pacific. Their speed was only 24 knots, but under good weather conditions they were able to operate a small number of fighters, fighter bombers and anti-submarine aircraft. Later, in 1944, when we were mastering the U-boat campaign, the "Albion" carriers were laid down—larger vessels with a speed of 30 knots which was essential for landing-on the heavier aircraft then coming into service. The introduction of jet aircraft after the war raised new problems. The growing weight and size of these machines necessitated increasing the strength and size of the catapult and the time arrived when there was no margin left for the still heavier aircraft of the future. Fortunately, this difficulty was overcome by the steam-operated catapult—a British invention—capable of launching the heaviest carrier-based aircraft likely to be required by the Royal Navy.

But there still remained the problem of landing-on and the need for a large parking ground. It looked as if the heavy carrier of the future would have to be at least as large as the "Eagle" and "Ark Royal." The "Eagle" cost some £16,000,000 and the cost of the "Ark Royal" will work out at much more, probably at about £24,000,000—alarming figures when compared with the cost of the pre-war "Ark Royal" of some £3,500,000.

Once again, however, a British innovation—the angled flight deck—has gone a long way to provide the solution. The conventional shape of the flight deck has been modified by extending it to permit aircraft to fly-on at an angle of 8 deg. to 10 deg. to port, relative to the ship's fore-and-aft line. The forward area of the deck is thus left clear as a parking ground and the aircraft landing-on can fly-off again to make a fresh attempt if it has failed to hook on to one of the arrester wires.

Thus, although high speed is still necessary for landing-on, it is now possible to obtain in carriers of the "Albion" class the performance required to operate all types of aircraft likely to be used by the Royal Navy. This class, all recently completed or about to complete, cost only about £10½ million—not an exorbitant price these days for ships which are to provide the striking power of the Royal Navy. Why, then, are the Americans building 60,000-ton carriers costing over £70,000,000?

British and United States views on the primary function of the heavy carrier differ because of the different basis on which their two navies are being trained. Our carriers must be large enough and fast enough to operate at the utmost speed modern jet fighters, fighter bombers and anti-submarine aircraft, for actions between surface ships, to provide air support for troops during amphibious operations and to locate and destroy submarines and long-range bombers attacking our trade. For us, we must never forget, the safeguarding of the sea communications is vital.

The United States Navy, on the other hand, is being trained to fight a land power from air-sea bases — to attack inland targets with large, heavy, medium-range bombers (thus reinforcing strategical bombing by long-range shore-based aircraft) and to land troops by helicopter and aircraft. For the United States safe communications make it possible for their Navy to fight from air-sea bases, and also ensure ultimate victory by safeguarding reinforcements and supplies from across the Atlantic to Europe. But they are not a matter of life and death as they are to this country.

The decision to build these super-carriers was, in fact, only arrived at after the most heated arguments between the United States Navy and Air Force. Indeed, were the Royal Navy to ask for mammoth vessels of this kind, there would be some justification for the current controversy on the value of the heavy carrier. For ships of 60,000 tons are sufficiently valuable to offer tempting targets for guided nuclear missiles. In any event, as we are leaving strategical bombing to the Royal Air Force, it would seem preferable from an operational point of view to have three carriers of about 20,000 tons—rather than one three times the size—to provide a given number of aircraft.

FLYING ARRANGEMENTS IN "ARK ROYAL"

H.M.S. "Ark Royal" is 803ft 3in in length with a peace-time complement of 110 officers and 1522 ratings (exclusive of her squadron personnel). Modifications have been made to her design during construction and she now has the angled deck, steam catapults, a stronger and new type of arrester gear, a deck edge lift in addition to central lifts and the mirror deck landing aid (a device for landing-on aircraft without a directing officer), hangars with an improved type of ventilation and a special aircrew refreshment centre. The 5½ deg. angled deck has reduced the number of arrester wires to six and enables crash barriers to be dispensed with (except in the case of an aircraft losing its hook). The deck edge lift is situated amidships on the port side and serves the upper hangar. There are two lifts on the centre line. This contributes in a major way to the flexibility of the flight deck work and the speeding up of flying operations. The improved ventilation in the hangars, coupled with the reduced danger arising from the use of kerosene for jet aircraft, greatly facilitates aircraft maintenance work. When aviation spirit was in use in the old-style hangars it was necessary to hold up maintenance throughout the hangar when there was any likelihood of sparks igniting the fumes. In "Ark Royal's" hangars only a small section near an aircraft being fuelled has to be treated as a "fuel danger" section. The introduction of an aircrew refreshment centre will enable pilots and observers to rest and refresh themselves before a flight; in previous carriers they had to travel some distance and climb down a number of steel ladders for their meals; thus, not an inconsiderable strain was imposed upon them at a time when it is desirable for them to conserve their energy, and there was the possibility of delay if they were suddenly required for an unexpected operation.

GENERAL ARRANGEMENTS

The "Ark Royal's" armament consists of sixteen 4·5in guns and forty-five smaller guns. In constructing the hull, electrical welding has been used on the widest possible scale to provide the lightest and strongest structure possible. Cammell Laird and Co., Ltd., was responsible for the main machinery, which consists of a four-shaft arrangement of geared turbines. Fuel for the aircraft is to be stored in several groups of tanks dispersed throughout the ship in such a manner as to reduce the risk of fire to a minimum. Magazines for storing all types of airborne weapons will be in other protected parts of the ship, from which items such as heavy bombs can be raised by a special lift. The distilling capacity of the ship is 350 tons per day. All the latest radio and radar devices are fitted, both for the navigation of the ship and for the control and direction of her aircraft and guns in both good and bad weather.

ELECTRICAL INSTALLATION

In order to meet the large demands for electrical power a generator capacity of 4000kW is provided. There are four steam turbine and four diesel-driven sets, each rated at 500kW and dispersed throughout the ship to minimise the effects of action damage. A 220V d.c. ring main system, incorporating approximately 350 electrically operated circuit breakers, is used for the distribution of electrical power. Control of the supply and distribution systems is effected from a large main switchboard, and in an emergency from four smaller switchboards, each controlling a quarter of the ship. Continuity of supply for the vital services of the ship is ensured as far as possible by the duplication of supplies fed through automatic or hand-operated change-over switches. Rapid restoration after failure of both normal and alternative supplies may be carried out by means of an emergency supply system. More than 1000 motors are installed. They range in size from 170 h.p. machines driving the forward capstans down to fractional horsepower motors for such varied services as ice-cream making, workshop tools, oil purification and air conditioning. This number includes nearly 600 for driving the ventilation fans, which maintain an adequate supply of fresh air throughout the ship.

Approximately 10,000 lighting points are installed, 3000 of which are fitted with twin 20W fluorescent tubes. Part of this installation consists of red lighting to allow for rapid adaptation of vision at night. In the event of the normal lighting supplies being put out of action following severe damage to the ship, battery-operated emergency lanterns are automatically switched on to facilitate movement about the ship. A novel feature of the electrical installation is a system which provides supplies for starting and servicing naval aircraft. It comprises a number of fixed motor generator sets, with their associated control gear, feeding socket outlets on the flight deck and in the hangars. It obviates the need for cumbersome batteries and trolleys. Since there are about 1300 compartments in the ship, electrical communications are of great importance. Some 1500 telephones are installed, 500 as out stations on an automatic exchange, and the remainder, mostly sound powered, as out stations on direct telephone systems. Where necessary amplified speech communications are installed. These take the form of individual intercom or talk-back systems for navigational and action communication and involve the fitting of over 100 loudspeakers. In addition to the foregoing, an integrated main broadcast system is fitted. General information, warning signals, &c., are passed over this system to all parts of the ship. In action, the various departments of

the ship can take control of appropriate units of the system, e.g. the armament broadcast unit by gunnery personnel, the flight deck and hangar broadcast unit by flying personnel, &c., and in these conditions only warning signals from the main system can override transmissions on the unit system. Approximately 600 loud-speakers are installed.

Photographic Facilities

The ship's photographic section is considerably smaller than a laboratory ashore, but it is capable of dealing with a large variety of demands. It is fitted with the latest equipment, which has been specially designed to save space and weight and to operate under adverse conditions. A universal processing machine, occupying only 12ft by 2½ft of deck space, can develop and dry all widths of film in use in the Service from 16mm to 9½in wide. The process can be carried out at a speed as fast as 1200ft per hour. Vibration-free enlargers will operate with the ship travelling at full speed and in any kind of sea. With the large stocks of photographic material carried in refrigerated compartments, the "Ark Royal's" photographic material may serve as a central processing laboratory for other ships in a striking force.

Investigation into the Failure of Two 100MW Turbo-Generators*

No. I

By SIR CLAUDE GIBB, C.B.E., D.Sc., M.E., F.R.S.†

It has often been said of engineering that "Progress is made by solving the problems resulting from the making of progress." This paper describes investigations made following the failure of two generators, each of 100MW capacity, installed in the Richard L. Hearn Generating Station at Toronto of The Hydro-Electric Power Commission of Ontario. The author details some general considerations affecting the design of alternator rotors, the selection of materials used, past troubles which had to be avoided, reasons for certain features incorporated in the original design and modified as the result of the failures, and safeguards introduced into current practice to avoid the possibility of a repetition of the failures.

The designers of large-output turbo-type generators have long accepted the fact that the dimensions of the revolving field or rotor primarily determine the basic design of the generator, and that there are many more problems arising from rotor design than from the stator.

One of the first and fundamental questions arising is the material to be used for the rotor end bells (or end caps or retaining rings as they are variously called). Fig. 1 shows the original

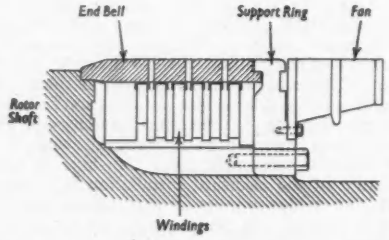


Fig. 1—Original arrangement of rotor end winding supports

design of the rotors concerned in this investigation. The end bells concerned are shown shaded. For mechanical strength, the designer would prefer to use a relatively low alloy steel which would provide the desired physical properties after hot forging and simple heat treatment. Such end bells would, however, be magnetic and introduce difficulties with both rotor and stator because the leakage fluxes at the ends of the stator core would be intensified, thus augmenting the core end-section and core end-plate heating and also causing eddy-current surface heating in the end bells. In addition, the leakage of flux from the rotor into the end-bells would increase the main flux densities in the rotor body and thus increase the current in the rotor windings required for magnetisation.

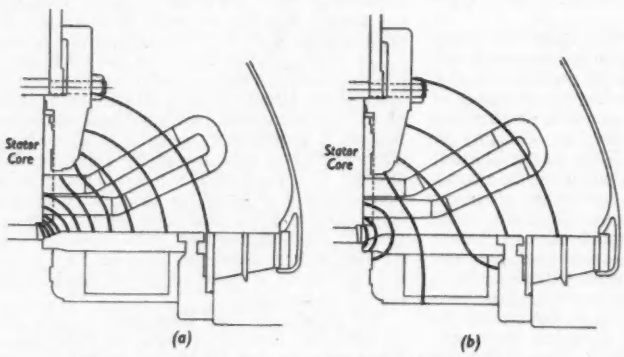
Considerations of desirable magnetic paths call for end bells to be of non-magnetic material and this demand has led to intensive metallurgical research in many countries seeking the most suitable material. Scores of alternative alloys and materials have been considered, amongst them being titanium and a variety of nickel copper (monel) alloys.

The material which has been most widely used is an austenitic steel of the following approximate composition :—

Carbon, per cent	0·64 –0·70
Silicon, per cent	0·37 –0·45
Manganese, per cent	7·23 –8·18
Sulphur, per cent	0·006–0·014
Phosphorus, per cent	0·020–0·032
Chromium, per cent	3·80 –4·09
Nickel, per cent	8·40 –8·83

The material from which the end bells of the rotors in question was made lay between the limits given above. Such a material gives considerable advantages to the electrical designer but provides major problems for the metallurgist, the forgemaster and the machinist.

Fig. 2 illustrates the way in which the more important component of leakage flux at the ends of the rotor and stator core is affected by the rotor end bell material. The intensity of



(a) With magnetic end bell. (b) With non-magnetic end bell.

Fig. 2—Stator end leakage flux paths

the leakage field is indicated by the spacing of the lines depicting the flux path, and clearly demonstrates the effect of the longer flux path with non-magnetic end bells in reducing the field intensity. For the sake of clearness the leakage field is drawn only for the air path and it will be understood that the flux path is completed in the iron portions of the magnetic circuit in a direction normal to the plane of the paper. A flux distribution as shown in Fig. 2 (*b*) has so many advantages in large generators that the designer seeks them vigorously and presses the metallurgist continuously to obtain better and better physical properties from non-magnetic materials.

In the smaller-output generators, built prior to about 1930, magnetic end bells were generally used, and at the time non-magnetic bells became available a yield point of only 35 tons per square inch was adequate to meet the operating stresses then applied. With the rapid growth in size of generators, there came the need for improved physical properties and the commonly demanded yield point was stepped up to 40 tons, 45 tons and, finally, to 50 tons per square inch. The specification to which the Toronto end bells were ordered was :—

Yield point, tons per square inch, minimum	50
Ultimate tensile strength, tons per square inch, minimum	57
Elongation on 2in length, per cent minimum	20
Reduction of area, per cent minimum	30

Acceptance tests on the Toronto end bells are given in Table I.

The disadvantage of non-magnetic bells is that as the material is austenitic, the physical properties required can be obtained only by cold working (actually warm working), and not by heat treatment. This cold working inevitably produces residual stresses in the finished ring, since the improvements in physical properties are a consequence of grain structure distortion. Depending upon the technique of manufacture adopted, the residual stresses resulting from cold working almost certainly will vary considerably from end bell to end bell, and from forgemaster to forgemaster.

The method of manufacture adopted depends upon the facilities existing, the forgemaster's

Table I—*Acceptance Tests on Toronto End Bells*

Machine No.	Serial No.	Cast No.	Yield point, tons per sq. in	Ultimate tensile strength, tons per sq. in	Elongation, per cent	Reduction of area, per cent
1	FB.1333	64139 A2	50·6	57·0	38·0	44
1	FB.1345	64139 A3	48·8	56·2	42·0	49
2	FB.1346	64139 A4	49·8	56·8	38·0	51
2	FB.1377	65699 A1	56·2	61·0	29·5	42
3	FB.1476	67137 A	63·2	64·0	6·0	19
			53·0	57·8	20·0	28
			55·8	60·0	18·5	30
3	FB.1648	71269 A3	49·6	56·2	39·0	43
4	FB.1505	65699 A	55·4	60·6	23·0	32
4	FB.1378	65699 A2	59·0	63·2	23·5	38

past experience and his opinions on the quality of the final product. Expanding on tapered mandrels may lead to greater residual stresses than forging under a hydraulic press while on a mandrel, but there is room for further and more definite information on this point which is being obtained by continued research. Rolling is a preferred method, always provided that the rolls are capable of exerting a load sufficient for the cold work to penetrate through the full thickness of the end bell, since otherwise the inner and outer surfaces would be stretched, placing the centre of the thickness in severe tension which would remain as residual stress—the worst possible condition for resisting the hoop stress due to its own mass and the stress produced by the end turns of the rotor windings.

To produce end bells of the dimensions [outer diameter, 58¾in ; inner diameter, 52¾in ; overall length, 21¼in] required for the Toronto rotors a 4000-ton press was not powerful enough to forge over the full axial length after partial cold working, and the forging tool was restricted in working to approximately one-third of the length of the end bell by tilting the mandrel. Thus, for satisfactory rolling, the force exerted between the rolls for Toronto-size end bells would have to approach 12,000 tons and such a rolling mill would involve fantastic bearing loading problems which have not, as yet, been solved. A design of a rolling mill is, however, under active consideration.

The Toronto end bells were forged under a 4000-ton press by the following method :—

(1) The ingot is cogged into a billet in a number of heats, forging being carried out between 1100 deg. and 900 deg. Cent.

(2) The billet is cut into blocks under the press.

(3) The blocks are flattened (upset) and the central hole punched and drifted under the press. The shape is trued by flattening and edging.

(4) Hot expanding is carried out on a mandrel in two stages.

(5) The forgings are cooled and rough machined.

(6) Expanding by forging under the press on a mandrel is carried out after heating to 1050 deg. Cent. and allowing to cool to 480 deg. Cent. when forging commences.

(7) Stress-relieving prior to machining by heating for five hours at 400 deg. Cent. and cooling in the furnace.

When the end bells for Nos. 1 and 2 generators were produced item (5) above was not current practice. It was, however, carried out on end bells for Nos. 3 and 4 generators.

Late in 1952 the machining allowances in the bore, after cold working, were increased to remove the material having the highest residual stress, tests having shown that the high internal

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* Abstract of paper. Institution of Mechanical Engineers, London, February 15, 1955.

† Chairman and Managing Director of C. A. Parsons and Co., Ltd.

stresses present in the bore decreased rapidly below the surface.

Another problem which has been prominently in the designer's mind for many years is whether or not to drill ventilating holes through the end bells. Such holes, shown in Fig. 1, appreciably lower the temperature rise in service, but weaken the bell and are potential stress raisers, particularly in a work-hardening non-magnetic material. The designer must make his choice between two evils and his decision will be influenced by previous experiences.

It was known when designing the Toronto generators, that they were to be used to take the peak loads on a system predominantly supplied by hydro-driven generators and were likely to be varied in load from 10 to 100 per cent maximum rating two or three times each day, and to be shut down each night. Conditions more likely to produce coil distortion could hardly be visualised and much thought was devoted to limiting rotor temperature rise.

The final decision was to provide ventilating holes, since rotors of similar design, although of smaller capacity but higher rotational speeds and similar stresses, had been in service for many years, all completely without any form of trouble. The potential danger of ventilating holes was fully appreciated and allowed for in design and in manufacturing technique. Carefully sharpened drills were used and great care taken to radius the holes at the inside and outside surfaces of the bell.

Description of Units Concerned

The Hydro-Electric Power Commission of Ontario (generally known as Ontario Hydro) ordered four units each of 100MW similar in most details except that Nos. 1 and 3 sets were to be dual frequency units, i.e. originally to operate at 25 c/s and then as conversion of the Hydro system to 60 c/s proceeded, to be converted to generate 60 cycle current.

Machine No.	Date of order	Date on load
1	February 1, 1949	October 28, 1951
2	February 19, 1949	February 4, 1952
3	November 14, 1950	November 24, 1952
4	November 7, 1950	June 10, 1953

The two dual-frequency sets with two-pole rotors ran at 1500 r.p.m. to give 25 c/s and were converted to give 60 c/s by changing the stator connections and providing new four-pole rotors running at 1800 r.p.m. No 1 unit was converted and recommissioned as a 60 cycle set on August 31, 1953, and ran until it failed on April 1, 1954.

Particulars of the service history of Nos. 1 and 2 sets are given in Table II.

Table II—*Service History of Nos. 1 and 2 Sets*

	No. 1	No. 2
Number of hours in service :		
25 c/s	6,916	
60 c/s	4,427	10,739
Total	11,343	
Total kilowatt-hours generated × 10^6		
25 c/s	197,390	
60 c/s	370,129	685,199
Total	567,519	
Number of starts :		
25 c/s	75	
60 c/s	25	77
Total	100	
Number of overspeed trip tests :		
1695 r.p.m., 25 c/s	10	
1980 r.p.m., 60 c/s	7	17

Table III—*Details of Tests to Determine Effect of Shutting Down at Night*

Unit	Date, 1954	Length of shut down		Time to run up from rolling gear	
		Hours	Minutes	Hours	Minutes
No. 1	March 19th	6	35	1	5
	March 26th	7	43	—	42
	March 30th	7	27	—	52
	April 1st	8	4	—	22
No. 2	March 23rd	8	4	—	38

During the latter part of March, 1954, tests were made to determine the effect of shutting down for short periods at night, and some details are given in Table III.

No abnormal vibration was experienced during these tests.

The number of runs under the above conditions is comparatively few and the cycles of stress and temperature to which the end bells were subjected are not likely to have had any significant effect.

Fig. 3—Damage on Toronto No. 1 unit

These sets operated under peak load conditions. For example, on No. 2 set on December 19, 1952, during the night the load was steady at about 10MW, rising to 90MW at 7.45 a.m. to 9 a.m. and to 100MW from 10.30 a.m. to 12 a.m. The load was dropped to 10MW at 12.30 p.m. until 4 p.m. when it was again increased to over 100MW at 5 p.m., which was maintained till 7 p.m. The load was reduced to 20MW at 8 p.m. and the set taken off the bars at 9 p.m. for the week end. During the week the load was normally maintained at 10MW during the night.

The temperature of the rotor body and the end bells is dependent upon the losses in the rotor windings. The rotor body has a much greater heat capacity and, therefore, could follow the load changes only slowly, whereas the end bells would respond rapidly, being cooled directly by the cold inlet gas. The coefficient of expansion of the end bell austentic steel is 65 per cent greater than the rotor steel and the variations in temperature would cause a corresponding change in the shrink of the end bells on the body and in the stress in the bells owing to this shrink. Superimposed upon the main stress in the end bells this fluctuation could be a minor contributory factor to the failures.

Occurrence of Breakdowns

No. 1 Set.—The first failure occurred on No. 1 set at 6.14 a.m. on April 1, 1954. The machine had been shut down during the night of March 31st to April 1st and was run to speed in twenty-two minutes in the early morning. The generator was synchronised at 5.55 a.m. and the load built up to 10MW, when at 6.14 a.m. an apparent explosion occurred. Flames immediately appeared at the exciter end of the generator and a major fire rapidly developed around the generator and foundation block. It was thought at first that a hydrogen explosion had taken place inside the generator, but from the subsequent examination it was clearly evident that the original cause was a mechanical failure in the rotor at the exciter end. The immediate result of the severe mechanical forces, caused by the disintegration of the rotor, fractured the bearings, supports and housings, gas seals and oil pipes at both ends of the rotor, releasing cooling gas and lubricating oil which flowed freely around the generator and foundation block. A major oil fire developed and was fed from the auxiliary oil pump which was automatically brought into operation when the main oil pressure fell as the turbine speed fell through the set being automatically tripped by the protection gear (Fig. 3).

Damage external to the generator, caused by the fracture and breakage of bearing housing, pedestals, main driving coupling, and other parts, was relatively minor. Practically all the damage to auxiliaries, busbars and cables, structural work and building was caused by the fire in which approximately 3000 gallons of oil were consumed. Owing to the excellent efforts by the station operating personnel, despite extremely difficult conditions and hazards, the effects of the fire were limited mainly to the area of No. 1 set. At the same time the remaining turbo-generators Nos. 2 and 4 sets were shut down without harm to the turbo-generators, boilers or auxiliary equipment.

No. 2 Set.—After the fire on No. 1 set was finally controlled with the assistance of the city fire department, service was restored to No. 4 set. As the station service supply is common to Nos. 1 and 2 sets, temporary connections had to be made to No. 2 set auxiliaries from No. 3 unit. No. 2 set was put back into service during the early morning of April 2nd. Both these units were operated to meet system load requirements and the running conditions were normal. The sets were shut down for a period during the week end and both were restarted during early morning of Monday, April 5th. No. 2 set was synchronised at 5.18 a.m. and as the mechanical and electrical performance was normal, the load was built up to the full output of 100MW by 8 a.m. This load was maintained until 10.58 a.m. when, without warning, a heavy thud was felt, followed immediately by excessive vibration and a similar sequence of events as had occurred with No. 1 set. The mechanical damage to the bearing housing was not as extensive as with No. 1 set but oil feed and drain pipes were loosened and shaken off by the excessive vibration, allowing oil to be discharged over the area around and beneath the generator. The auxiliary pump was shut down at an early stage and the oil fire was not as prolonged. The amount of oil consumed was about 1800 gallons and the damage to auxiliary equipment was considerable. It is likely that hydrogen gas escaping from the damaged seal at the exciter end was first ignited and in turn set fire to the escaping oil. It was quite clear from the examination of the generator later that there had been no hydrogen explosion or fire inside the stator casings. It was afterwards found that some hydrogen gas was still retained in the casing of No. 2 generator which had to be scavenged with CO_2 gas before it could be opened for examination. No. 4 set was taken out of commission pending the result of the investigation, and pending a decision on the modifications to be made to the rotors of Nos. 3 and 4 sets.

(To be continued)

B.E.A. Electricity Bulk Supply Tariff.—The British Electricity Authority has given notice of a revised tariff for the supply of electricity to the twelve Area Boards in England and Wales for the year ending on March 31, 1956. As hitherto, the tariff incorporates a fixed charge per kilowatt of maximum demand and a running charge per unit consumed. It applies to all Area Boards on a uniform basis, subject only to regional fuel cost adjustment. Both the fixed kilowatt charge and the running charge remain the same as in the present tariff, which came into force on April 1, 1954, but the fuel price adjustment figure, which in that tariff had been reduced from 0·0007d. to 0·00065d. per penny variation in the cost per ton of fuel in the respective areas, has been further reduced to 0·0006d. An innovation in the tariff is a provision for adjusting the kilowatts of maximum demand to which the fixed kilowatt charge applies, if the sum of the demands on the Central Authority varies by more than 1 per cent from the estimate of total demands on which the kilowatt charge in the tariff has been based. In such event, the chargeable kilowatts of maximum demand for each Area Board will be determined by adjusting their actual demand inversely as the sum of the actual demands varies from the estimated total demand. This provision will ensure that during the year of account the fixed kilowatt charges in aggregate will correspond approximately with the Authority's fixed costs of supply during the year, regardless of any variations between the estimated and actual total demands, due, for example, to extreme weather conditions, and will minimise the effect of such variations upon Area Board trading results.

THE ENGINEER

Vol. 199 FEBRUARY 18, 1955 No. 5169

LEADING ARTICLES—
Britain's Nuclear Power Programme 238
Unnecessary Secrecy 238

ARTICLES—
Alarm Clock Factory. No. II. (Illus.) 241
Automatic Indexing Machine for Measuring Gear Tooth Pitch Errors. (Illus.) 229
Electronic Digital Computers. No. I. (Illus.) 232
High Power Spark Erosion Machine. (Illus.)... 222
H.M.S. " Ark Royal "... 235
Industry and the New Towns 221
Investigation into the Failure of Two 100MW Turbo-Generators. No. I. (Illus.)... ... 236
Measuring and Control Instruments for Efficient Combustion 221
National Inspection Council for Electrical Installation Contracting 233
National Institute of Agricultural Engineering... 221
Power Farming Conference 221
Programme of Nuclear Power 246
Prospects and Problems of Rocket Propulsion for Aircraft. (Illus.) 246
Railway Engineering Projects. No. I. (Illus.) 226
Report on the " Comet " Accidents. No. I ... 234
Royal Society of Arts Prizes 221
Smoke Plumes and Gas Washing 240
Smoke Plumes from Chimneys 213
United Nation's Technical Assistance 221
Wind Tunnel Developments. No. I. (Illus.) 244

AMERICAN SECTION—
Restoration of the Saugus Ironworks in Massachusetts. (Illus.)... 250
Turbine-Driven High-Speed Dental Handpiece. (Illus.) 252
Tunnelling Machine at the Oahe Dam. (Illus.) 252

LITERATURE—
Books Received 239

OBITUARY—
David A. Bremner 239

NEWS AND NOTES—
Books of Reference 232
British Patent Specifications. (Illus.) 255
Catalogues 256
Contracts 254
Forthcoming Engagements... 256
Industrial and Labour Notes 253
Launches and Trial Trips 256
Personal and Business 254
Technical Reports 249

BRITAIN'S NUCLEAR POWER PROGRAMME

Events have clearly been moving very fast in the nuclear power field. It is only six months since the Atomic Energy Authority came into existence; it is less than five months since the Harwell Reactor School was set up. The Calder Hall station, the first attempt at generating nuclear power for the grid is still under construction; Dounreay station has hardly progressed beyond the preliminary design stages. Yet the Government has been bold enough to formulate the programme for the building of nuclear power stations that is described in a White Paper issued last Tuesday. The policy is wise, too. For it has long been recognised that the secrecy that has so long shrouded the development of nuclear power should be broken, that industry must be brought into the picture and that further advance will be all the more rapid technically when several teams, instead of what amounts at present to a single team, are working upon the development of design. The White Paper indicates Government awareness of the facts that there is a potential of great value to this country's export trade if we can rapidly develop industrially the " know how " of nuclear power station design and construction; and also pronounced advantages for the development of power in this country. For, ever since the years immediately following the war, it has become increasingly obvious that to raise the output of coal from the mines at a rate at all commensurate with the rising demand for fuel is going to be very difficult. There has, too, been a disparity between the plans of the British Electricity Authority, making high demands for coal, and those of the Coal Board, which have never been so optimistic. Upon the basis of reasonable calculations of future electricity consumption the Authority has looked like demanding, within twenty years, 100 million tons of coal a year—about two and a half times as much as at present. The White Paper indicates that, through the development of nuclear power, the demand for coal for electricity generation may level off in the sixties at about 60,000,000 or 70,000,000 tons per annum, and thereafter possibly fall.

Sir Christopher Hinton, who we learn as we go to press, has just been awarded the James Clayton Prize by the Institution of Mechanical Engineers, estimated about a year ago in a lecture before that Institution that the cost of generation of power in nuclear stations would be about one penny per unit, very substantially above the figure at present ruling in coal-fired stations. In the White Paper, however, the cost is estimated at 0·6d. per unit, corresponding closely to the cost in a modern conventional station. It is not reasonable to suppose that so large a difference can be accounted for by technical progress in the interim. It is more probable that it can be traced to an assessment by the Government of the value of the plutonium that is produced as a by-product of the generation of power in a thermal reactor such as that under erection at Calder Hall. This material can be more easily separated from Uranium 238 than can Uranium 235 and it can be used to enrich Uranium 238 for thermal reactors or be employed in fast reactors of the Dounreay type. Indeed, it is made clear in the White Paper that the rate of future development of nuclear generating capacity is in part dependent upon the production of this plutonium. In fact, not only high technical skill has gone into the planning of the programme of nuclear power development but a great deal of wisdom, too. For the concentration of work, at first, upon gas-cooled reactors in which the technical problems to be faced are less difficult to solve, will result in a more immediate ability of industry to come to grips with the problems of designing and building power plants; and at the same time it will help to build up stocks of fissile material, as a by-product of power generation, which can later be used for possibly more advanced types of reactor employing liquid coolants. Those later types of reactor may turn out to be cheaper and more efficient generators of power. But much greater demands are made by them upon further research.

The provisional programme for the construction of power stations is summarised on page 246 and in our next issue more substantial extracts from the White Paper will be printed. But apart from the decision to start to construct two gas-cooled graphite modulated stations about mid-1957 we do not think the rest of the plan can be regarded as anything approaching a defined programme. It really amounts to an assessment at this date of what, upon present inadequate data, ought to be possible at various dates in the future. Very much depends upon factors that are at present unknown, like the actual observed performance of the Calder Hall station and the rate of progress in research. Still more depends upon the rate at which industrial firms which will supply the plant can build up teams of nuclear power plant designers with sufficient knowledge to begin to make contributions of their own to the advancement of techniques. But if the programme cannot really be taken very seriously at present that does not alter the significance of the fact that a tentative programme has been drawn up. Progress may turn out to be more rapid or less rapid than is at present expected; we hope it will be the former. But the important things to notice are that the drawing up of a programme is evidence of energy in the Government; that there is evidence of close co-operation between the Government, the Atomic Energy Authority and the British Electricity Authority; that there is evidence, too, of the interest industrial firms are taking in the matter; and that there is a clear intention to press development urgently even at some risk that, to begin with, power may not be generated quite as economically in nuclear as in coal-fired power stations. That is a wise intention. For there is probably no country in the world that stands more to benefit from gaining early experience of the construction and operation of commercial nuclear power stations than Britain, where indigenous sources of fuel supplies are becoming more difficult to work and where prosperity depends so largely upon the selling of skill, technical knowledge and productive capacity to the world at large.

UNNECESSARY SECRECY

It is to be hoped that Parliament will continue to press for a Government statement on the development and production of guided missiles. We have known for the past two years that most of our aircraft manufacturers are making components for them, but it is only now, under pressure from Parliament, that the Government has admitted how very much further behind we are than the United States, which has at least six guided missiles of various types now in service in her armed Forces. In this country contracts have been placed for the production of air-to-air rockets, but the more important surface-to-air rocket is still in the development stage. Work on guided missiles since the war has been carried out in the closest secrecy—allegedly on security grounds—and the nation is thus in no position to judge whether this lack of progress is due solely to financial considerations or to hesitation and want of confidence

in the effectiveness of the missile for anti-aircraft defence. It is true that eighteen months ago, Mr. Duncan Sandys, the then Minister of Supply, assured us that no bomber could hope to outmanœuvre the guided rocket under development. But his encouraging announcement was not supported by subsequent statements from other Ministers, and it was soon forgotten when information was released of the devastating effects of the hydrogen bomb. This was followed by an aftermath of wishful thinking—that the hydrogen bomb would be an effective deterrent to war or that it would be kept in the background for use as a retaliatory measure. The possibility of any effective defence against it received no official encouragement. Our only hope in the event of war lay in a bomber offensive—to destroy Russia's capacity for bombing by air bombardment of her airfields and industrial areas.

The Supreme Allied Commander, Europe, believes that in the event of aggression he would be able to hold the Soviet armies with the aid of nuclear weapons. This means that Britain would be out of range of offensive guided missiles, for the 1000-mile supersonic guided rocket is not a reliable weapon of the immediate future. Britain, however, is an essential base for reinforcements, supplies and offensive operations, and there is little doubt that a large proportion of Russia's immense bomber force would be concentrated at the outset on attacks against this country. If, therefore, bombing operations are to be carried out from these islands, we should surely give priority to the defence of the bases from which the United States atom bombers are to operate, rather than to the construction of more bombers to add to their number. Indeed, unless the public are given some alternative to tit-for-tat bombing—some assurance of reasonably effective protection against the nuclear bomb—it is difficult to see how they can be persuaded to co-operate enthusiastically in civil defence measures. The position is very different in the United States. There the public have been assured that 100 sites for Nike missiles—an anti-aircraft guided rocket with a range of 30 miles—will soon be ready for action for the protection of thirteen major cities and that other large towns will be similarly protected at the earliest possible date. A site, it should be noted, is a battery of four launching platforms. In addition, 1200 interceptors in the 600-mile-per-hour class are available to shoot down intruders with conventional or rocket weapons. And a former Chief of Staff of the United States Army has expressed the view that these Nike missiles can be relied on to bring down a bomber flying at 60,000ft. No doubt we cannot in peace time do things on such a large scale, but it would be an immense encouragement if the Government would announce that defence measures of a similar kind are envisaged for this country.

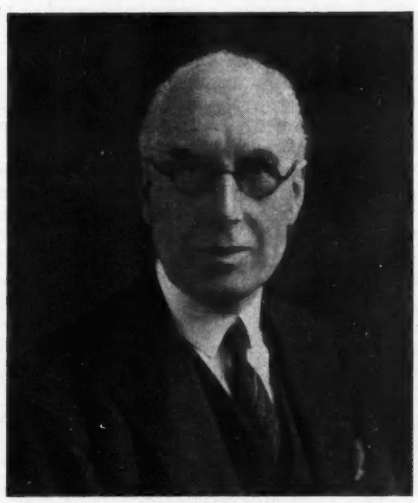
The position regarding air-to-air missiles seems somewhat better. The "Sparrow" and the "Falcon"—guided missiles with a range of 5 miles—have been in use for some time by U.S Navy and Air Force fighters respectively, but, as mentioned above, it is now known that contracts have been placed by the Ministry of Supply for the production of air-to-air missiles. With the impending abolition of the Anti-Aircraft Command structure, however, it is not enough to rely entirely for our home defence on high-flying manned fighters, and it is urgently necessary that the production of surface-to-air missiles should be given the utmost priority. There seems no longer any reason for the British Government to hesitate, in view of the confidence which the Americans place in these missiles as an effective anti-aircraft defence measure. Two U.S. heavy cruisers are to rejoin the Fleet in the summer with their secondary armament completely converted to fire surface-to-air missiles and the Navy Bureau has recently let it be known that plans are in hand for the conversion of a number of destroyers to fire the new and still classified ram-jet "Talos," and the 14ft "Terrier," with a range of 10 miles. In that connection, it would do much to stimulate public interest in guided missiles if we followed the American practice of giving names to those under development and of declassifying the main features of those which are in use, or about to be used, in one of the fighting services.

Obituary

DAVID A. BREMNER

ALTHOUGH it is now some years since Mr. David Alexander Bremner retired, his work as director of the British Engineers Association is well remembered by engineers and industrialists. We deeply regret to record his death, which occurred on February 7th at his home at St. Margaret's Bay, Kent. He was in his eighty-ninth year.

As a young man, David Bremner, after training in mechanical and electrical engineering, gained valuable experience in various appointments overseas. They included the positions of electrical engineer to the Port Said Suez Coal Company, electrical engineer



David A. Bremner

of the Borough of Kimberley, mechanical and electrical engineer to Torry and Company, in Johannesburg, and chief engineer and general manager of the Simmer and Jack Gold Mines. Later on, Mr. Bremner spent several years in Scandinavia as general manager of the Dunderland Iron Ore Company, in Norway, and general manager of the Hydraulic Power and Smelting Company, Trollhattan, Sweden. Among his many accomplishments was a mastery of Swedish and Norwegian, languages which he spoke and wrote fluently. When he settled again in this country, just prior to the first world war, Mr. Bremner became a managing director of Chance and Hunt, Ltd., Oldbury. During the first world war he served with the Ministry of Munitions as director of non-ferrous metals supply.

At the end of the war Mr. Bremner was appointed director of the British Engineers Association. He actually took up his duties in that office on January 1, 1919, and for the ensuing twenty-five years brought not only experience but abounding energy and enthusiasm to his many tasks. Under Mr. Bremner's guidance the Association became increasingly recognised as a national organisation in the engineering industry for the promotion and protection of British engineering interests at home and abroad. Two things in particular may be recalled in connection with Mr. Bremner's directorship. They are the development of the British Engineers Association's bulletins, containing valuable tables and comments about current industrial trends, and the organisation, during the years between the wars, of monthly luncheon meetings at which matters of importance to the engineering industry were presented. Mr. Bremner himself was a lucid speaker and on several occasions made valuable contributions to the proceedings of these meetings. In addition, he was responsible throughout his term of office for the preparation of many memoranda submitted to Government departments and other bodies on numerous aspects of the engineering industry's policy and affairs. Furthermore, his work for the B.E.A. and for the industry which it represents required Mr. Bremner to serve on a number of councils and committees, in the deliberations of all of which his advice and comments were always welcome. He was a member of the grand council of the Federation of British Industries, of the British National Committee of the World Power Conference, of the British National Committee of the International Chamber of Commerce, and of various committees of the British Standards Institution. He also took an important part in the organisation of the Palace of Engineering at the British Empire Exhibition at Wembley in 1924, and for some years thereafter was the vice-chairman of the committee of experts formed to advise on the Engineering and Marine Exhibition held biennially at Olympia. Mr. Bremner was elected to membership of the Institution of Mechanical Engineers in 1900 and of the Institution of Electrical Engineers in 1894.

David Bremner retired in 1943, when he was approaching his seventy-seventh birthday, and although he retained a lively interest in affairs, his visits to London naturally became less and less frequent in recent years. He spent a long and distinguished career in the profession and industry of engineering. In the course of it he made a host of friends in this country and overseas. Those who remain remember keenly his arduous and successful work, and they remember, too, his unfailing courtesy and geniality.

Books Received

Questions and Answers on Diesel Engines. By E. Molloy. London: George Newnes, Ltd., Tower House, Southampton Street, Strand, W.C.2. Price 6s.

Electrical Equipment in Mines. Edited by H. Cotton. London: George Newnes, Ltd., Tower House, Southampton Street, Strand, W.C.2. Price 50s.

Magnetic Alloys and Ferrites. Consulting editor, M. G. Say. London: George Newnes, Ltd., Tower House, Southampton Street, Strand, W.C.2. Price 21s.

Smoke Plumes and Gas Washing

On page 231 of this issue we summarise a paper on "Effects of Velocity and Temperature of Discharge on the Shape of Smoke Plumes from a Funnel or Chimney," by L. W. Bryant and C. F. Cowdrey, presented at the Institution of Mechanical Engineers last Friday. Here we print in abstract remarks made by some of the speakers in the discussion. Since the matter has relevance to the controversy about the advantages and disadvantages of gas washing at power stations, we have chosen, mainly, to print those parts of the discussion that have a bearing on that question.

MR. C. H. BOSANQUET : I think it is rather a pity that the authors did not occupy more of their space in giving more results of their excellent measurements, including certain actual specimens of their traverses, for both velocity and temperature, through the plume. On the other hand, I consider that much of their theory needs a certain amount of re-examination. Their equation, which gives the rate of increase of diameter with distance, may be a very excellent interpolation formula for use over their experimental range, which was 1ft from the chimney, but it must break down if one tries to extrapolate it. It is an interpretation formula only. It can be taken as an article of faith that if one has diluted the smoke by a factor of 100 or so, it will then be practically motionless relative to the surrounding air, just lifting with the wind, and its subsequent rate of change of diameter will depend on wind conditions, the diameter and, possibly, the amount of heat in the plume, and it can depend on nothing else. However, from the equation we get the extraordinary conclusion that by the time the plume has grown to some ten times the chimney diameter we get a rate of increase which is varying inversely as the rate of emission from the chimney, inversely as the square of the plume diameter and directly as the fourth power of the chimney radius. How can the chimney radius have anything to do with the rate at which the plume grows when it has drifted a mile downwind ? The formula is an interpolation formula only and has no physical meaning whatever. Apparently, the authors have used this curious formula in deducing the curves which give the chimney effects which no one has ever reported. It just does not happen. Somebody would have noticed it already if the height to which the plume rose was a very violent function of the chimney radius. In contrast, Sutton's formula applies to a drifting plume and predicts a rate of expansion which varies as something between the inverse tenth root of the diameter and the inverse fourth root according to the turbulence conditions in the atmosphere. Pure molecular diffusion gives the inverse first power, which is an absolute limit. The inverse equation is quite impossible in any conditions. The trouble is that there are three ill-defined regions in a smoke trail. First, just as it comes out of the chimney, the conditions are almost entirely governed by the velocity of efflux. After some considerable time when it has been well diluted, the conditions are governed by the wind. In between we have the transients, and one cannot extrapolate measurements that are all in the transient and jet regions. It is as difficult as working out the range of a bullet from time and distance measurements taken in the first 6in of travel down the barrel and forgetting that it ever comes out. I consider the measurements themselves to be extremely valuable, although I am afraid that I disagree completely with the deductions drawn from them.

Mr. Lucas : I join with a previous speaker in saying that I find it hard to believe that the width of the chimney has a marked effect on the concentrations produced by a hot plume. In the case of a cold plume with a given mass flow one can understand easily enough that if one restricts the chimney exit diameter one has a greater efflux velocity and greater concentrations downwind. However, I find it difficult to understand how, when dealing with a hot plume, a variation in the width of the chimney will give one different concentrations at various distances downwind. Another point that I should like to raise is the question of the density of the gases leaving the chimney at a station where the plume is washed. In their paper the authors have assumed that the density is the same as the density of the atmosphere. I should like to question that very strongly. If one is dealing with a power station from the point of view of carbon dioxide content alone the plume gases will be some 6 per cent heavier than the surrounding atmosphere. In addition, not only is the gas saturated, but, as one can see if one watches the Bankside power station, the plume is heavily laden with very tiny particles of water. I have done some preliminary calculations on the subject which have yet to be verified, but it seems likely that the mass of the water according to circumstances will change the density of the plume a further 5 to 15 per cent, so that in an extreme case the density of the plume may be very much heavier than the density of the atmosphere. In that case, one has to apply a correction of the same type as to a hot plume, but on the opposite side, and since the distance downwards is so much less than the distance upwards the effect of the correction is very marked.

Speaking as a member of the B.E.A., I think it is generally recognised that the B.E.A. is somewhat nettled by the attitude taken by the Beaver Committee in so far as it presented the B.E.A.'s views on the subject of gas washing merely to contradict them flatly. I welcome this paper as presenting a very great body of information on this subject, and it is presented from an unbiased point of view. It seems to me that the evidence in the paper gives very considerable support to the B.E.A.'s point of view that the introduction of gas washing for all stations would not only mean the expenditure of a vast amount of money, which can be considered, but would not lead to any reduction in atmospheric pollution. The paper states that the critical wind speed is about 15 m.p.h. I put it to the meeting that if the wind speed of this country were invariably over 15 m.p.h. the subject of atmospheric pollution would never be discussed in a learned society of this kind or anywhere else, for the problem would not arise. Where the proportion of SO_2 is one, two, three, four or perhaps more parts per million, that is when the problem of atmospheric pollution arises. Those are the concentrations which produce the corrosion of which the Beaver Report gives details. If SO_2 is a menace to health, it is under those circumstances that the problem arises. The paper gives a large number of details as to the sort of concentrations of SO_2 which can be produced in the vicinities of power stations, and the highest figures that one can find in the paper where there are 300ft stacks, which are more or less standard inside the B.E.A., are of less than one part per million, and one part per million is somewhere around the critical figure for SO_2 concentration. If the concentration is distinctly below one part per million, nobody or nothing—human beings or other things—will suffer. It is when the concentration is above one part per million that trouble occurs. Therefore it seems to me that the case to be considered is the case when the wind speed is lower. On the occasion of the great smog disaster when, many deaths were caused, there was not a wind speed of 15 m.p.h.; at times the wind speed was very near to zero, and that seems to me to be the root cause of the trouble. If one considers a washed plume from a power station with extremely low wind speeds, then the washed plume itself can be a menace ; but again, as pointed out in the paper, a hot plume produces a negligible concentration.

Professor P. A. Sheppard : I think that the paper gives a very false impression of the importance of wind speed in the problem of concentrations downwind of factory chimneys. At no stage do the authors bring out the point that the action of the wind is twofold. It has a diluting action and a diffusing action. The diluting action is really all-important if there is any appreciable wind. As previous speakers have suggested, by the time you have a wind speed of 15 m.p.h. the problems are very nearly solved for you because the smoke is being stretched out at the rate of 15 miles in the hour instead of only, say, 2 miles in the hour. Moreover, with regard to high winds or moderate to high winds, the authors give curves for winds greater than 15 m.p.h. as inevitably rather turbulent, so that you win on both counts, the dilution factor being strong and the spreading effect being strong. It is the low wind condition which is particularly important, because it is the low wind which not merely fails to dilute the smoke, but is also commonly non-turbulent. I thought the authors were a little misguided in making so much of the chimney diameter. I quite see that it was a relevant length parameter to fit the data relating to the initial motion from the chimney axis, but a much more relevant foot-rule for the interpretation of observations of this kind would be the chimney height. This certainly is a relevant parameter in regard to the spread after the initial motion from the chimney.

Dr. R. S. Scorer : It is a very common thing for plumes to divide into two. Therefore the cross-section of the plume is nothing like circular, and in that case a lot of the arguments which depend upon the plume being more or less circular break down completely.

(The speaker showed contrasting slides to illustrate buoyancy and turbulence effects.)

This slide is a photograph of a Derbyshire cement works. The hillside in the background is 700ft above the bottom of the valley, and the picture is taken from about 400ft above the plume. It is a very hot plume. It has a momentum, but it has negative buoyancy because the surrounding air is so warm, and so it sinks back again and fills the valley below the level indicated with smoke. This slide shows the same chimney under almost identical wind conditions. The chimney can be seen, and there is a light wind drifting to the left, but the plume is sufficiently buoyant to go up to about 3000ft, and it forms a cloud at the top. The cloud rose and drifted away with the wind. That is the same chimney with the same fuel consumption in both cases.

Here is a photograph of Battersea power station, and the hot plumes can be seen going up. No doubt they contain a terrible amount of sulphur dioxide, but it is all going up. One plume contains only one-tenth of the amount of sulphur dioxide, but it is coming straight down towards the observer and is obscuring the chimney stack. It also obscures the flats. I went to the top of the flats, and the whole plume was passing below me.

Mr. G. Nonhebel: The first matter that I wish to discuss is really Mr. Cowdrey's film in which he showed that the eddying went down the side of the chimney. That is quite a common effect to be observed in the case of many mill chimneys in the northern manufacturing districts, where one can see the blackening of the chimneys, and it is a very important factor even in the case of a power station because if it happens with a power station it is in effect lowering the effective height of the chimney for at least part of the gas. This effect, known as downwash, has been described by Stalker, of the University of Michigan (Ref. *Mechanical Engineering*, Vol. 62, page 459 (1940); University of Michigan *Research Bulletins* Nos. 29 and 38, Hohenleiten *Trans. A.S.M.E.*, Vol. 64. Downwash is distinct from down draught caused by a building. Stalker showed that increased velocity of the discharge would obviate the effect, but his work is by no means complete because he did not discuss the shape of the mouth of the chimney. The point that I wish to make is that the N.P.L. should study the shapes of chimney mouths. Some chimneys are belled out, while some are cut off straight. The object of the belling-out is to stop smoke running down the wall of the chimney. It is by no means certain that the correct design is known. When I entered this room this evening, somebody told me that the effect is seen at one or two power stations just outside London. The second point that arises from the observations made by Mr. Bryant and Mr. Cowdrey and deduced theoretically by Dr. Bosanquet, can also be deduced from the work of the United States Atomic Energy Commission Unit at Oak Ridge. It is that the smoke plume will rise to a height very nearly proportional to the quantity of flue gas going up the chimney, up to, in the case of large flues, 1,000,000 cubic feet per minute.

We have been shown pictures of the power station at Fulham. I should like to have confirmation from Mr. Bryant that had the flue gas from the four chimneys been combined in one, there would have been a very much greater height of thermal rise. One would have a greater heat content going up the chimney. The result of calculations that we have made indicates that one gets very nearly the same ground level concentration from one chimney taking four times the amount of gas as from one chimney taking a unit volume of gas. If one distributes the gas to four chimneys, the ground level concentration will be multiplied by four. In that case one has increased the quantity of gas by four and the amount of soot by four, and if the chimneys are in line with each other and fairly close, they will multiply the ground level concentration by four. There has been a great deal of talk about flue gas washing in respect of one particular process, that operated at two London power stations. That process cannot be operated anywhere else inland in this country. Therefore, if there are any further power stations inland where there is to be flue gas washing, one would have to recirculate the water. At the two power stations referred to, Battersea and Bankside, the gas washing process is a once-through system and the gas is cooled practically down to the temperature of the river. However, in the case of a recirculating system the gas is cooled not to anything like the same extent but to about 48 deg. Cent. In fact, it is cooled just to the wet bulb temperature of 52 deg. Cent. The gases then have a very appreciable buoyancy. Consequently, a lot of the discussion about the ill effects of gas washing falls to the ground in respect of future power stations. It is highly desirable to discharge the gas at as high an economic velocity as one can, which is probably about 60ft per second, in order to get a velocity rise component and in order to make certain that the gas is clearing the stack properly. Finally, in connection with the remarks made about gas washing, I know the difficulties about the downwash from the plume, but if one can avoid that, then it must be realised that, as Mr. Bryant said in his remarks about his paper, the area of ground covered by a concentration of SO_2 is very much less with gas washing than when there is no gas washing. The area with gas washing is about one-tenth of that with no gas washing. That makes a considerable difference when one is considering the quantity of sulphur which is coming down in a very highly populated area such as London, Birmingham or Manchester. I cannot understand Mr. Lucas's chemistry when he says that one part per million of SO_2 is a critical limit below which one will get no corrosion if the sulphur is dissolved in rain water. That cannot be so. Any sulphur dissolved in rain water, whether one part or half a part per million, will rapidly be converted into sulphuric acid, and that will be corrosive.

The Chairman, in proposing a vote of thanks to the authors: the only regrettable thing about the meeting seems to me to be the fact that the empty seats were not filled by Members of Parliament. It would have been a very good thing if they had been because of the topical nature of the paper.

Alarm Clock Factory

No. II—(*Concluded from page 193, February 11th*)

The alarm clock factory of Smiths English Clocks, Ltd., at Wishaw, in Scotland, is now producing over 2,000,000 alarm clocks a year. In order to attain this high output extensive use has been made of modern production equipment with specially developed machines for component manufacture and assembly. An elaborate assembly conveyor system is equipped with clock movement assembly fixtures and on it much of the work is carried out whilst the assembly is moving.

ACTUAL assembly of the clock movements starts at the machine illustrated in Fig. 7. On this machine the steel false plate, on which the dial plate of the clock is later fixed, is assembled to the brass front plate using the four main pillars of the movement. The machine has an annular indexing table with twenty-four loading stations, and two operators standing on the left-hand side of the machine take the parts from hoppers situated on the centre of the table.

Each loading station has on it a profiled block, into which the four pillars are loaded. A front plate is first placed on the block, then the false plate is placed on it and spigots on the four pillars project through their mating holes. The table indexes and carries this assembly to a pneumatic squeeze riveter fitted with four punches, which operate simultaneously to rivet all the pillar feet whilst the two plates are held tightly together. As the assemblies pass out of the riveter they are inspected and placed in the trays of an overhead conveyor, which transfers them to the head of the main assembly line. This conveyor carries a buffer stock, and the assemblies circulating on it are only removed as required.

The main movement assembly lines consist of a number of interconnected carrousel conveyors—this type of conveyor, it may be mentioned, consists of a continuous chain of platforms moving on a closed circuit at a convenient height to provide a progressive assembly bench. With this arrangement and the special equipment fitted on the conveyors much of the work is carried out whilst the assemblies are moving along on the conveyors. On each conveyor a certain fixed number of parts are fitted and at the end of that series of operations the movement is inspected and transferred to the head of the next conveyor, which overlaps or adjoins. Transfer of a movement for subsequent operations from one conveyor to the next can only be made by an authorised inspector, and thus a continual check is maintained at all stages of assembly.

Main assembly starts with the placing of the front plate assembly, face downwards, on jigs fixed on the conveyor platforms. In the first stages the centre wheel and other pinion and wheel component assemblies for the time and alarm trains are placed in their holes in the front plate by operators at successive stations. Finally the brass back plate is fitted to the movement, after which four nuts are placed on the pillars and given half a turn.

Fig. 7—Indexing table machine for assembling false plates to clock front plates and riveting movement pillars

The movement is then carried through the machine illustrated in Fig. 8, for the screwing down of the pillar nuts. This machine consists of a bridge with longitudinal bar guides carrying a sliding body with four air-operated nut screwing heads. As the jig enters the machine projections in the sides of its base contact latches on the sliding body and

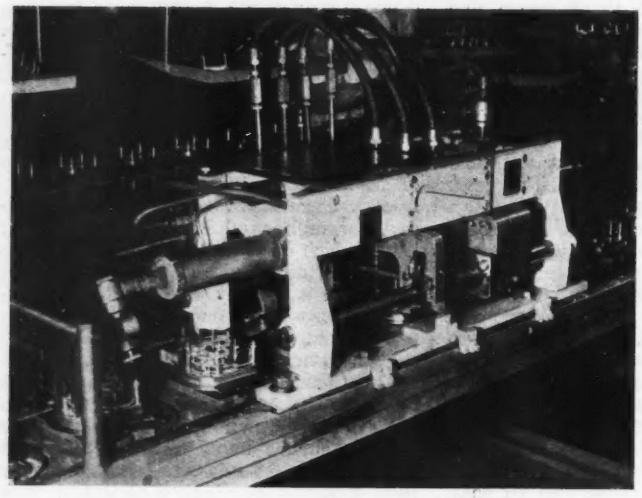


Fig. 8—Movement assembly conveyor machine for screwing down four pillar nuts. The nut screwing head is drawn along by the conveyor whilst the nut drivers are in operation

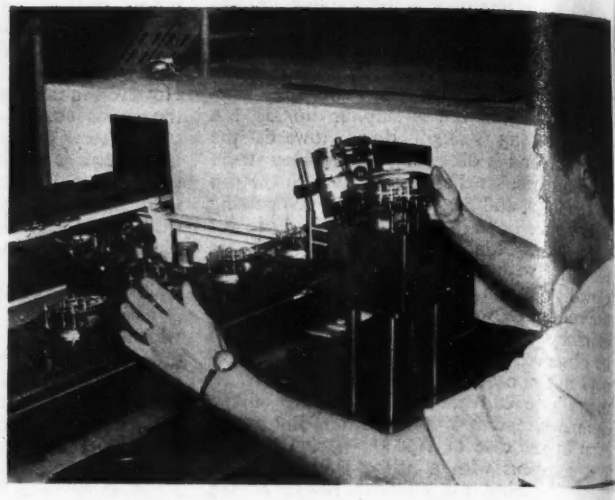


Fig. 9—Movement oiling station where all points on the back are lubricated in one operation

move it along the bridge at the same speed as the conveyor. During this movement of the jig through the machine a sequence of air control valves are operated. First the nut screwing heads descend and run the nuts down the pillars to their locked position. At the end of the body movement along the bridge, by which time the nuts are screwed fully home and the heads retracted, the latches are automatically tripped to release the sliding body. At this point air is admitted to a pneumatic cylinder, the piston of which draws the body back to the entry side of the bridge, ready for the entry of the next jig and with its latches reset. A gauging bridge at the entry side of the machine ensures that all parts of the assembly on a jig are correctly positioned. If any component is out of alignment it contacts the gauging bridge and the conveyor is automatically stopped.

On the subsequent conveyors the movements are carried on moulded rubber fixtures designed to provide a shaped " nest " for the assembly as it is progressively fitted with the alarm motion, balance, &c.

One of the most critical processes in the whole of movement assembly is the fitting of the balance and hairspring sub-assembly to the escapement. This stage of the work takes place at the end of the main assembly conveyor, and when the movement is assembled so far as its time and alarm trains are concerned, but is, as yet, without its mainspring or dial. The operators who fit the balances complete the whole process, selecting the balance from a special supply conveyor, placing it in its conical bearings in the clock movement, adjusting the bearing screw, and pinning up the outer end of the hairspring.

A supply of complete balance and hairspring sub-assemblies is carried on a circulating conveyor which passes along above the movement conveyor at the point where the balances are fitted (Fig. 10). This conveyor is provided with special trays designed to carry the rather delicate balances without any risk of damage. As each movement on the main assembly conveyor arrives in front of the operator at the balance fitting station, she takes a balance and inserts it straight into the movement. This obviates putting the balance down on a bench or in a tray and so cuts out a possible cause of damage.

Having offered the balance to its correct position, the operator adjusts the bearing screw to give just the right end-shake to the balance. This is done on a special tool, which enables the balance screw to be set with precision. Accuracy here is of particular importance, as the amount of end-shake of the conical male bearings on the balance staff in the female centre bearings in the balance screw and plug is critical in the action of the clock.

With the balance assembled into the movement, and the end-shake set, the next operator pins up the outer end of the balance spring by placing the end in a slot in a small pillar on the clock back plate and securing it by a wedge pin. With the spring pinned up, the balance is checked to make sure that it is " in beat " and " breathing " correctly, and the movement then passes on to the oiling processes.

The movements are oiled at all the necessary points on the front and the back plates on two fixtures, one of which can be seen in use in Fig. 9. Each fixture consists essentially of an oil bath in which the liquid is maintained at a constant level. A number of plungers, corresponding to the oiling points on the movement, are immersed in the oil bath and they are connected through a plate to a single spring-loaded spindle projecting above the level of the bath. The operator sets the clock movement between guide pillars and presses it down on the spindle. Depression of the spindle raises the oiling plungers to contact with the clock movement and deposit a predetermined amount of lubricant at the required points.

After the oiling station the movements are transferred to another conveyor section on which the main and alarm springs are fitted. This section adjoins the spring manufacturing machines in the central component making section. The springs are supplied in straight lengths with their ends ready formed and they are wound into the movements on special machines, one of which is shown in Fig. 11. The machine consists of two small compressed air motors driving heads which screw on to and rotate the spring arbors.

In the sequence of operations each spring in turn is clipped on to its spindle where its hole registers on the driving projection. When the air supply is switched on the spindle is rotated and the spring, guided by the operator, as shown in the illustration, is drawn into the movement. The hooked end of the spring is clipped on to the anchor column at the end of the winding operation as the air supply is switched off. When both springs are in position the air motor control lever is momentarily moved to the reverse position and the driving heads are unscrewed from the movement arbors. The final operation on the springs is the subsequent compression of the anchoring loop on its pillar by a hand tool.

On the next conveyor the completed movements, which are now ready for the attachment of the dial and hands before being placed in their cases, undergo a final complete inspection. Here any faulty movement is placed on a return run of

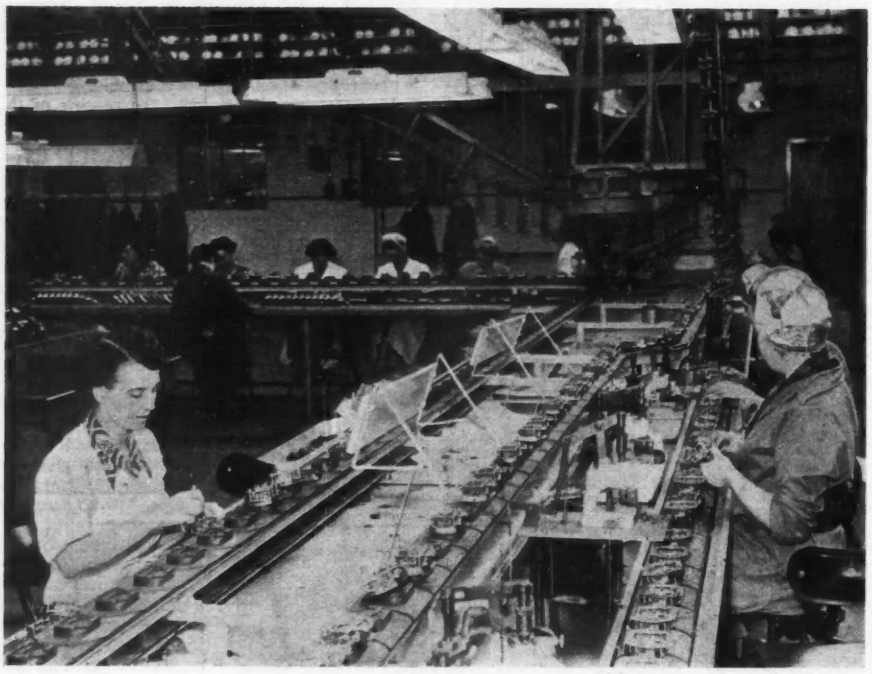


Fig. 10—End of movement assembly line with balance fitting station supplied with balance assemblies overhead tray conveyor

Fig. 11—Spring fitting station where the main and alarm springs are wound on to their arbors by compressed-air-driven heads

conveyor for the attention of reject operators, to whom the type of fault is indicated by the use of discs of different colours and shapes. This system saves time which would otherwise be required in writing out slips.

A supplementary conveyor which feeds into the main line at the next stage supplies the dials complete with the hour wheel pipe and hour hand. When these parts have been assembled to the motion the time side is synchronised with the alarm mechanism. The minute and alarm hands are fitted simultaneously in a special-purpose machine, in which the hands are located in their correctly synchronised position.

Fig. 12—Casing station where movements are fitted into cases complete with the glass and bezel, and the keys and case nuts are screwed on and the springs fully wound

The casing of the movements is carried out at the station illustrated in Fig. 12, where the overhead conveyor from the case sub-assembly area, previously described, descends to working level.

At this station the movement is dropped into the case and the glass and bezel placed on it. Then the operator loads the machine to be seen in front of her in the illustration. The table of this machine has let into it a group of spindles, two of which are recessed to take winder keys, four to take the nuts used to fix the movement on the back of the case. When the machine has been loaded with the keys and nuts the operator places the complete movement and case on its table. Depression of a pedal actuates a pneumatic ram at the top of the machine, which descends and with its padded head presses the bezel with its glass on to the case. A second pedal is then depressed and an air motor comes into operation to rotate the key and nut spindles in the table of the machine. These spindles screw up and tighten the four fixing nuts and screw on the winder keys. The winder key spindles also fully wind the springs of the clock ready for subsequent time testing.

For time testing the clocks are set at 12 o'clock at the final station of the main assembly line shown in Fig. 13. Along the front of this station is the working level run of a long overhead conveyor system which passes down the length of the factory. Suspended from the conveyor are frames with three platforms, and the timing of the conveyor drive is such that each platform frame passes the station once every twenty-four hours within an error limit of three seconds. The speed of the conveyor is controlled from a panel which receives impulses every second from a master clock. A geared mechanism driven from the conveyor is coupled to the control panel, and should the impulses received from the master clock not synchronise with the speed of the conveyor, automatic speed adjustment is made through a motor generator from which the conveyor driving motors receive their current.

The clocks taken from the assembly line and set at 12 o'clock are placed on the lowest platform of the conveyor. When the twenty-four-hour circuit is completed and a clock arrives once again at the loading station it has to be within five minutes fast or two minutes slow to be passed as suitable for dispatch. If it is acceptable it is transferred to the top platform of the conveyor, but if it is not it is re-regulated, re-wound and placed on the centre platform for a further twenty-four-hour circuit. If the timekeeping of the clock is within the acceptable limits at the completion of its second circuit it is transferred to the top platform, but if it is still keeping bad time it is removed from the system and sent to a rectification department.

The timing conveyor on the first part of its circuit after leaving the final inspection passes into the dispatch department. Here it descends to a position where the top platform is at bench level whilst the two lower platforms pass between screens. With this arrangement, whilst the acceptable clocks can be removed and placed on a belt conveyor leading to packing stations, the clocks in process of timing are inaccessible to the packers.

From the packing stations the boxes of clocks are transferred to a large warehouse, where a "floating" stock of some 100,000 clocks is maintained ready for immediate dispatch. This very large stock has been found to be the minimum quantity required to satisfy immediate delivery demands for the varying types and colours of clocks made in the works.

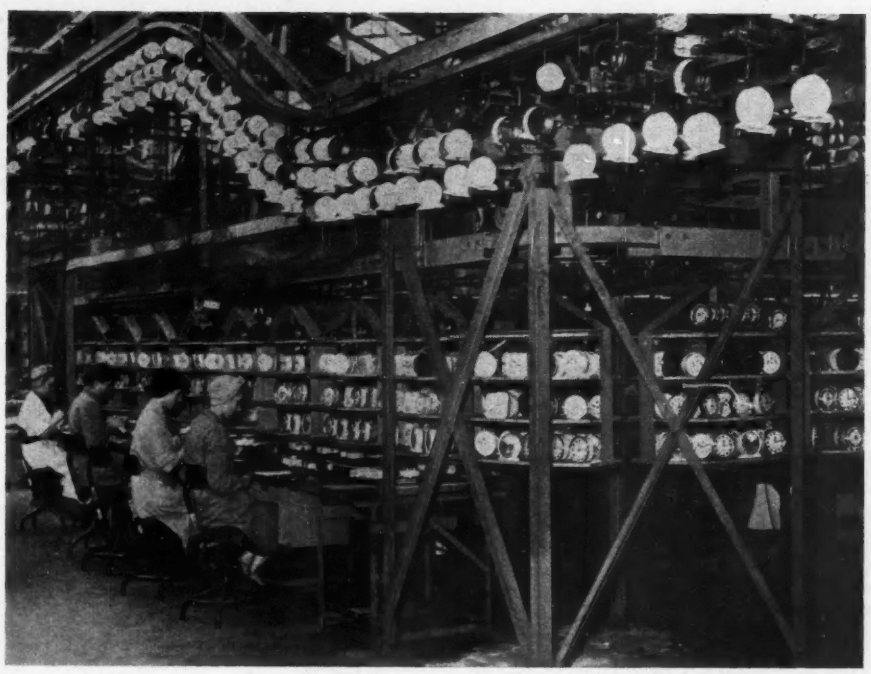


Fig. 13—Clock setting, timing and regulating station with three-platform timing conveyor

A service department adjoining the packing and dispatch sections deals with clocks returned to the works for rectification of damage in transit, and as a result of purchasers' complaints. We are informed that less than 1 per cent of the clocks dispatched are returned to the works as not complying with the guarantee, and a large majority of these returns are as a result of transport damage such as broken glass, scratches, &c.

Clocks returned as a result of mechanical failure are dismantled by skilled operators and a full report on the cause of the trouble is made on each movement. These reports are transferred to statistical analysis sheets, which are inspected so that any inherent faults which might develop can be eliminated at their source in manufacture, or even an improvement in design introduced.

The present output of 8000 clocks a day is obtained with a factory staff of some 800 hands. It is of interest to note, however, that in planning and equipping the works provision was made to enable this output to be considerably increased if necessary. The increase would be achieved by double shift working on the machines and by increasing the speed of the assembly conveyors, each of which is sufficiently long to permit the introduction of more operators.

Wind Tunnel Developments

No. I

At the Royal Aircraft Establishment, Farnborough, and the National Aeronautical Establishment, Bedford, a number of new wind tunnels have been, or are being, constructed. Others are being operated or adapted to exploit a new technique for working in the transonic region with slotted working sections. At Bedford, where much of the research on supersonic craft has been transferred, the research facilities include tunnels which in design and in respect of automatic measuring and instrumentation equipment compare with the most modern of those known to exist. The first two supersonic tunnels described here, bearing in mind the adverse relationship between model size and loadings and cost, are regarded as about the optimum size anywhere in the medium and large tunnel classifications.

DETAILS are given here of some of the more important post-war wind tunnel developments in this country which we were allowed to see during a very brief tour of the aeronautical research establishments at Farnborough and Bedford. Certain of the new wind tunnel installations are works of considerable engineering magnitude and some of the more impressive structural details we were able to note are here recorded. It should perhaps be pointed out that the aerodynamic characteristics of the most recent supersonic tunnels, both here and in America, which have been published, are not sufficiently complete to justify a comparison of their size or worth.

Although much of the structural work on the first three installations described belongs to the field of pressure vessel engineering and shipbuilding, many problems of a novel kind arose and new design and constructional techniques have had to be developed.

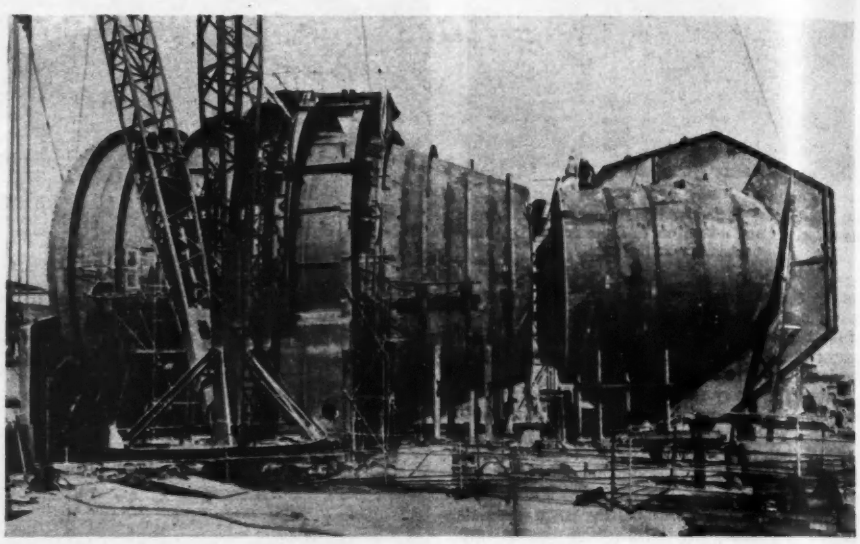
This is particularly true of the 8ft by 8ft supersonic tunnel now under construction at the National Aeronautical Establishment. The size of the actual fluid circuit and particularly of the area occupied by the power generating and air-conditioning plant associated with the tunnel, are well shown in our accompanying illustrations. The weight of the steel shell alone is 5000 tons.

It is a variable density tunnel with a speed range extending from zero to a Mach number of 2·7. Tunnel pressure can be varied between 4 and 0·1 atmospheres. The maximum power requirement of the compressor of 80,000 h.p. is supplied by electric motors. The main unit is an English Electric synchronous motor with a continuous rating of 68,000 h.p. It is operated at 50 c/s and supplied from the grid. The shaft speed is 755 r.p.m. and it can be clutched, through a step-up gear, to a double d.c. motor developing 12,000 h.p. The power-house itself includes the foundations for two 20,000kW gas-turbo-generators designed to supply the synchronous motor with power from 10 c/s to 50 c/s and thereby enable a variable compressor speed to be obtained. Precise control is effected through a Ward-Leonard set consisting of a 14,000 h.p. a.c. motor driving two 6000kW d.c. generators at 600 r.p.m.

The multi-bladed axial compressor has ten stages in series, the outside diameter being about 21ft, and a tapered drum, the maximum blade length being 2ft 6in. To accommodate the wide variations of pressure ratios and mass flow requirements over the whole speed range, the compressor has been split and six upstream stages can be completely removed, the air circuit being reclosed by a blank cylinder. To facilitate this operation there is bottom clearance for a rail mounted, multi-wheeled bogie on which the section can be rolled transversely from the circuit.

Representative of many impressive engineering details which we saw in our brief few minutes' inspection of the installation were those concerned with three major adjoining elements of the circuit—the cooling chambers and effuser, the working section and a variable geometry diffuser section.

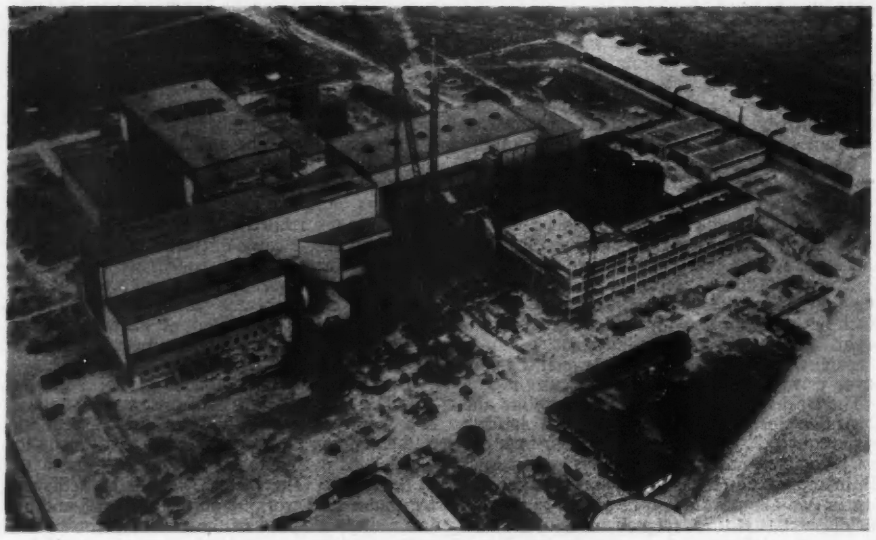
The cooling chamber is the section of largest diameter and is, in fact, 47ft in diameter. It encloses a large number of straight-through tubes through which the air passes. Water circulates around these tubes and the air, which attains a temperature of 140 deg. Cent. after compression, is cooled to 40 deg. Cent. It is then very rapidly effused over a relatively short curved profile section, the contraction ratio being of the order of 35 : 1. Contractions of this order and rate ensure the best possible flow conditions and account for the huge initial diameter of this element. The contraction leads to the throat of the convergent-divergent duct formed by the top and bottom walls of the working section, the two side walls being parallel. It will be appreciated that there is a fixed nozzle geometry for a given Mach number greater than unity. In nearly all wind tunnels provision is made for varying the Mach number by replacement of the profiled walls with those having a profile suited to each particular speed. As has been explained in connection with other tunnels, fringe Mach numbers associated with each nozzle can be approximated by hinging these walls so that small changes of wall alignment can be effected.



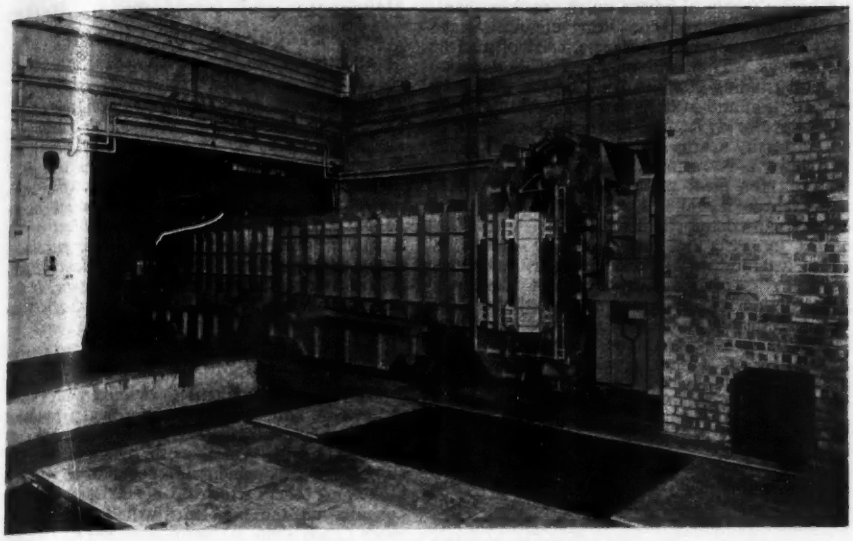
8ft by 8ft supersonic wind tunnel, showing part of tunnel circuit, including corner, cooler and settling chamber, during erection. The diameter of this section is 47ft

With the larger tunnels changing the nozzle characteristics in this way becomes a considerable engineering operation involving the lifting and securing of components weighing many tons. There is also the more obvious restriction imposed by such discrete steps in the speed range.

A distinguishing feature of the 8ft by 8ft tunnel at Bedford is therefore the achievement of stepless nozzle geometries by the use of a flexible wall nozzle section. Special steel plates, each 62ft long, 8ft wide and 1in thick, forming opposite walls of the section, are flexed to form any required nozzle geometry by thirty pairs of hydraulically operated jacks disposed longitudinally. Several American tunnels employ flexible wall nozzles. Each pair of screw jacks can exercise a thrust of up to 30 tons and they are operated by hydraulic motors. The very precise and remotely controlled setting of the profile is effected by the use of punched telegraph tape. Each plate, which was machined in France to close tolerances, is anchored at the downstream end to allow for its "growth" upstream. As the whole section is pressurised the plates are exposed only to the drop in stagnation pressure across the ends, the greatest value of this drop being never greater than 1 atmosphere.



The 8ft by 8ft supersonic tunnel at Bedford



Nozzle section, balance section and diffuser of the 3ft by 3ft supersonic tunnel. These sections are mounted on bogies and can be rolled from the circuit

The supersonic diffuser is also of advanced design. A wall diagram in the building suggested the use of a diffuser with a variable geometry. A wedge bridge piece was shown to effect supersonic diffusion through a system of oblique shock waves. Motor-operated screw jacks are then used to adjust the geometry of two of the diffuser walls, thus providing a second and variable throat.

The total weight of the bogie and diffuser is 1200 tons. Another reason for this mobility in the diffuser section is the possible future requirement for a transonic working section which would then replace the diffuser. The whole tunnel circuit is of welded construction with a 100 per cent weld X-ray inspection. Shell plate ranges from $\frac{1}{4}$in to $1\frac{1}{4}$in thick, primary structural steel being up to $2\frac{1}{4}$in thick. Special manipulators were employed so that weld fabrications of convenient lengths could proceed vertically, thus obviating overhead welding.

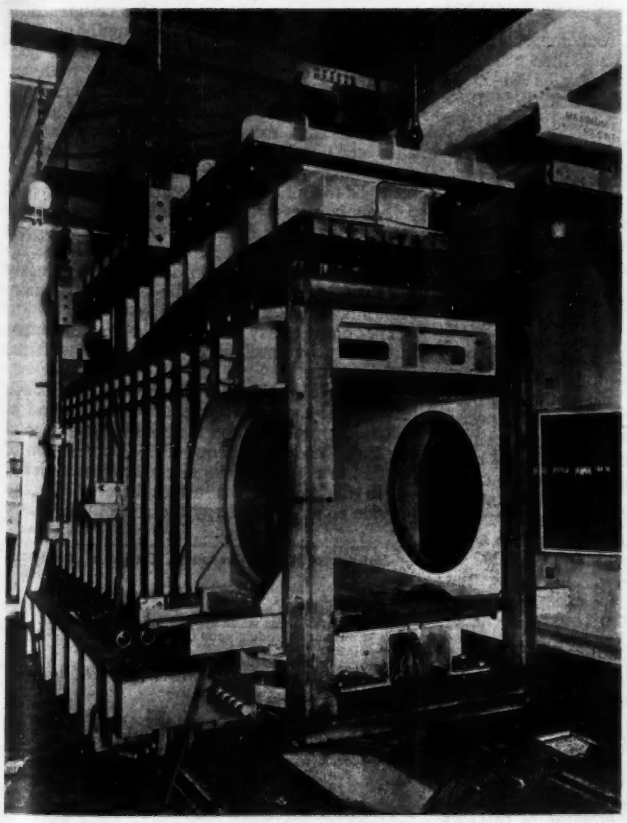
The flexible joints and supports to allow for thermal expansion are worthy of note. The circuit may be described as having two long legs which are 350ft long and two short cross legs 60ft long. With reference to the first illustration of the installation, the nearest long leg contains, from left to right going downstream, the supersonic diffuser, the working section and the combined effuser, cooling section and settling chamber. This latter section can be identified as the largest diameter section and it is anchored in all directions. The cross leg including the corner pieces, proceeding downstream, is pivotally mounted with freedom to rock and twist about 20ft from the distant long leg. This leg is itself anchored longitudinally at a point opposite to the cooler, but having freedom at that point to move transversely. The actual displacement amounts to about $1\frac{1}{4}$in, so that this distant leg is arranged to rotate through $^1/_{15}$ deg. about the upstream (left) corner. Both upstream corners are fixed in all directions. Expansion in each of the long legs between the two longitudinal fixed points which can amount to 5in is taken care of by an expansion joint in each. There is also an expansion joint in the cross leg (right). The concrete foundations at these anchors to carry the thrusts due to the internal air pressure are massive.

Most of the energy input to the tunnel is lost to the water circulating in the cooling chamber as previously mentioned. On the right of the illustration can be seen eleven water-cooling cells which have a total capacity of 3,000,000 gallons per hour. The quantity used in the 8ft by 8ft tunnel amounts to 1,000,000 gallons per hour. The air temperature at the cooling chamber is reduced from 160 deg. to 40 deg. Cent. At the throat the temperature can be as low as −100 deg. Cent., but because of the irreversible nature of diffusion across shock waves the temperature is raised to about 40 deg. Cent. in the subsonic stream.

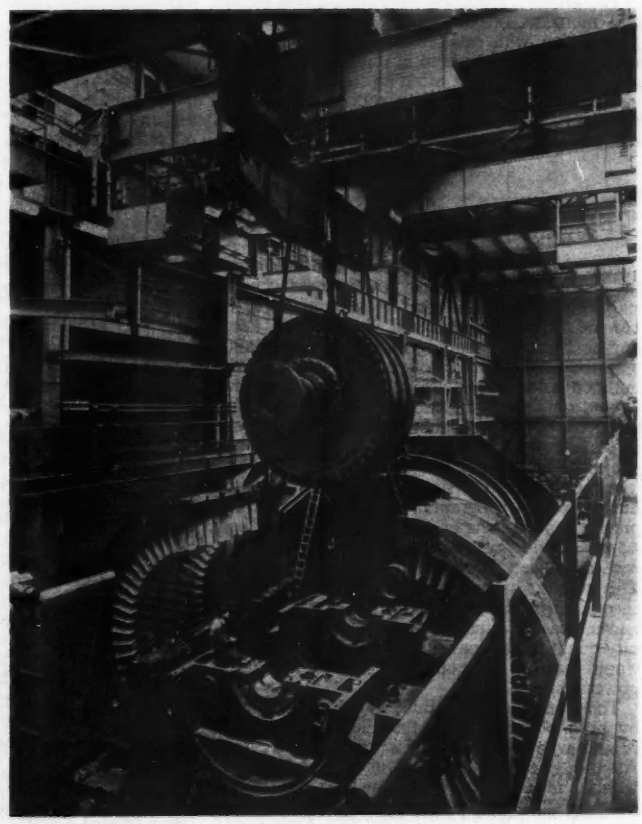
The auxiliary plant includes compressor and an evacuator plant (totalling over 8000 h.p.) for adjusting the tunnel pressure. The tunnel is partially evacuated when starting up to reduce the starting load. Part of the air is constantly bled off to a drying plant. The wind tunnel, measuring and fluid motion "visualisation" equipment has yet to be installed, but we understand that the working section will be observed remotely through periscopic and later through television installations. Other recording equipment will be similar to that described below, which we saw in operation on other tunnels.

The 3ft square supersonic tunnel at Bedford is already in full commission, and in some respects it was regarded as a prototype from which to assess the problems which might be expected with the larger 8ft by 8ft tunnel. It can take models up to 2ft wing span at Mach numbers up to 2.

The $\frac{1}{4}$in plate steel shell of the tunnel circuit



Details of the 3ft by 3ft tunnel working section, showing the teak liner of the asymmetrical nozzle plate and the system of hydraulic clamping



Ten-stage axial compressor under construction for the 8ft by 8ft supersonic tunnel. To suit the mass flow requirements at certain compression ratios six-stages can be removed and the tunnel circuit reclosed

has a maximum cross section of 19ft square, and the total structure weight is 500 tons. It is also of the continuous variable-density design, capable of working from high vacuum up to 2 atmospheres absolute. Details of the nozzle section, balance section and diffuser (total angle 5 deg.) are illustrated herewith. It will be seen that all three sections are mounted from bogies and can be manipulated according to the track system, which is also shown, to give access to the balance section. To effect this operation a rubber ringed compressible joint fitted with two double-acting hydraulic cylinders, and shown downstream of the diffuser, is opened, and the diffuser withdrawn and transferred to the side bays. A specially vented or slotted working section can be used with this tunnel for transonic testing. The principle involves reducing the mass flow at critical sections in the nozzle and at the same time preventing the reflection of normal shock waves from the nozzle walls.

It will be noted that in this tunnel different Mach numbers are obtained by changing only one nozzle wall, the other walls being rectangular. Although an asymmetrical nozzle doubles the length of the nozzle required it considerably simplifies the conversion operation. Nine of these nozzle walls are provided, each with a teak liner designed to provide speeds increasing in increments of 0·2 Mach number. The handling and clamping arrangements enable a change to be made in about fifteen minutes. Spring clamps are used which can be released hydraulically.

The power plant consists of two d.c. motors developing a total of 16,000 h.p. They drive a l.p. and a h.p. centrifugal compressor mounted in series and having intercooling and after-cooling. The motors and compressors were taken from a German wartime installation, and the whole plant is structurally isolated. The motors are supplied from grid-controlled mercury arc rectifiers for speed control.

Air is bled continuously from the circuit to a silica gel drying plant and the water content is maintained at between 0·0001 and 0·00015 per cent.

The usual cooling and tunnel evacuating plant is provided. The temperature at the working section is 40 deg. Cent.

The model is mounted from a sting and forces and moments on the model are measured, in conjunction with self-balancing potentiometers, by strain gauges mounted in the sting. Pressure plotting is carried out using capsule manometers and their associated dial readings are automatically photographed. Schlieven optical equipment is provided.

(To be continued)

Programme of Nuclear Power*

HER MAJESTY'S GOVERNMENT consider that the development of nuclear power has reached a stage where it is vital that we should apply it commercially with all speed if we are to keep our position as a leading industrial nation and reap the benefits that it offers. The programme outlined below is provisional and must be considered only as the best indication that can now be given of the probable line of development. Types of stations, numbers and dates are all subject to change.

Although the decision to go ahead with a nuclear power programme does not depend on precise comparisons of cost, the cost of nuclear power should not be greatly different from the cost of power from coal-fired power stations. This country has a rapidly growing demand for energy, particularly in the form of electric power, and increasing difficulty in producing the necessary quantities of coal. These facts by themselves would justify a great effort to build up a nuclear power system.

The stations will be built in the normal way by private industry for the Electricity Authorities,† who will own and operate them. The Atomic Energy Authority, as the only body with the necessary experience, will be responsible for giving technical advice on the nuclear plant. British industry and consulting engineers have as yet no comprehensive experience of nuclear technology. They will be faced with a major task in training staff, in creating the necessary organisation and in designing the stations. This work has already begun. Owing to its complexity and diversity teams drawn from several firms may have to be formed. The preparatory work will call for great efforts from all concerned, and even so it will not be practicable to start building any commercial stations before 1957.

It is intended that the Electricity Authorities and private industry should obtain as quickly as possible the practical experience in designing and building nuclear power stations that will be the necessary foundation for a big expansion in the later stages of the programme. The Atomic Energy Authority, while giving as much assistance and advice to industry as possible, will remain primarily a research and development organisation and will continue to design, build and operate pioneering types of power reactor. They will also be responsible for buying uranium, fabricating the fuel elements, processing the used fuel and extracting the plutonium from it. There will therefore have to be a continuous process of co-operation and of financial adjustment between the Electricity and Atomic Energy Authorities. The exact arrangements to be made are at present being discussed with them.

POWER STATIONS

The provisional programme for the construction of nuclear power stations‡ is as follows :—

(i) The construction of two gas-cooled, graphite-moderated stations (each with two reactors) would be started about mid-1957. These stations should come into operation in 1960–1961.

(ii) The construction of two further stations would be started about eighteen months later, i.e. in 1958–1959. These would also have two reactors each and would be similar in type to the earlier two stations, but should show an improved performance, particularly in heat rating. Each of the eight reactors in these early stations would have a net output of electricity of 50MW to 100MW so that the total output from the four stations, which should all be in operation by 1963, would be somewhere between 400MW and 800MW.

(iii) The construction of four more stations might perhaps start in 1960, and then a further four eighteen months later, say, 1961–1962. These might come into operation in 1963–1964 and in 1965. It is difficult to specify what type of station these would be, but it is probable that each station would consist of only one reactor, which would be much more highly rated than the reactors in the first four stations. The stations begun in 1960 might be developments of the gas-cooled, graphite-moderated type. The last four stations might be of the liquid-cooled type, which might by then have been developed sufficiently to be economically satisfactory. The total installed capacity of the eight stations in this group should be well over 1000MW.

The ten-year programme would provide a capacity of about 1500MW to 2000MW. By the end of the ten years this country would probably be needing new generating capacity at the rate of over 2000MW a year, and the new nuclear stations coming into operation each year would be meeting something like a quarter of this. On the assumption that nuclear stations would be used as base-load stations they would by 1965 be producing electricity at a rate equivalent to that produced by about 5,000,000 to 6,000,000 tons of coal a year. Assuming that the programme continued to expand rapidly, this contribution towards the country's energy needs should also rise rapidly thereafter.

The plutonium from the early reactors should begin to become available in 1964 at the rate of several hundred kilogrammes a year and would be available for enriching the fuel charges in later, probably liquid-cooled, reactors. These reactors would, in turn, produce plutonium and, being more highly rated, would produce it more quickly so that it would be available for a rapidly expanding programme of reactors requiring enriched fuel in the late 1960s.

* Extract from a White Paper under this title issued last Tuesday.

† These are at present the British Electricity Authority, the North of Scotland Hydro-Electric Board and the Northern Ireland Electricity Board. On April 1, 1955, the South of Scotland Electricity Board will come into existence and the Central Electricity Authority will replace the British Electricity Authority.

‡ The term "station" is used here to denote the smallest unit that is likely to be built. In practice more than one such station may be built on the same site.

Prospects and Problems of Rocket Propulsion for Aircraft

By A. D. BAXTER, M.Eng., F.R.Ae.S., M.I.Mech.E., F.Inst.Pet.*

In this analysis of rocket propulsion the author first compares the rocket motor with air swallowing engines and goes on to discuss its auxiliary use for assisted take-off, climb boosting, and level flight acceleration and its use as the main power plant. The problems of rocket motor design and performance were the subject of the section abstracted herewith. The paper concluded with a section concerned with the problems of propellant supply, starting and thrust control. It was read before the Royal Aeronautical Society on Thursday, February 10th.

ROCKET MOTOR PROBLEMS

MANY of the problems associated with rocket motors are similar to those of other propulsion units, but generally they arise in much more concentrated form. On the other hand, there are some problems which are peculiar to rockets alone and others which do not exist at all. To consider all the problems would entail much more space than is permissible in the present paper, and so the discussion will be confined to some of the more important ones, which have a direct bearing on the design and use of these engines.

As noted [earlier in the paper], motor weight and propellant consumption for unit thrust are of primary importance. These are influenced by numerous design factors, such as permissible gas temperature, pressure, combustion efficiency, heat transfer, methods of pumping propellants, of ignition, cooling, thrust variation, and so on. Before examining these it will be useful to consider the layout of the main components and their functions. It is not proposed to deal with solid propellant motors, which are of relatively short endurance and only suitable in aircraft applications for assisted take-off, nor with liquid monopropellant forms which generally will be of lower performance than bipropellant motors.

Separate fuel and oxidant tanks are used and feed pipes lead from them to the respective high-pressure pumps. The propellants are then delivered to the combustion chamber through some form of control valve. One component is led into a cooling jacket surrounding the chamber and thence to the burner head : the other goes directly to the burner head where both are injected in such a fashion that rapid mixing and combustion occur. The large volume of hot gas generated then expands through a convergent-divergent nozzle to give the characteristic supersonic rocket jet. An alternative to this arrangement is to omit the pumps and feed the propellants by pressurising the tanks with a suitable compressed gas. This method gives a lighter overall weight of motor for short durations, but for operating times of more than thirty to sixty seconds, depending upon the thrust, it is more economical to use a pumping system.

The pumps may be driven by a small gas turbine or by mechanical connection with the main engine.

Specific Consumption.—There are two basic reasons for the high propellant consumption of the rocket motor. The first is the fundamental one that the oxidant required for combustion of the fuel is carried by the aircraft and not picked up in flight from the atmosphere. Thus, to provide equal heat energy the rocket must carry

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Notation.

A_1—Nozzle throat area.
a—Weight of items which are independent of pressure.
b—Constant depending upon operating pressure.
E—Thrust.
I—Specific impulse (lb/lb/sec).
K—Universal gas constant=2778ft-lb/deg. Cent. lb mole.
L^*—Length of chamber=$\frac{V_c}{A_1}$.
M—Molecular weight of combustion per pound.
P_1—Combustion gas pressure (lb/ft² abs.).
P_2—Exhaust gas pressure (lb/ft² abs.).
q—Specific propellant consumption, including turbo-pump consumption (lb/hr/lb).
T_1—Combustion gas temperature (deg. K).
t—Operating time.
V_c—Combustion chamber volume.
v—Jet velocity (ft/sec).
W_m—Motor weight.
W_p—Propellant weight.
γ—Ratio of gas specific heats at constant pressure and volume.
η—An empirical efficiency factor≈0·9.

at least an additional weight of oxygen sufficient to burn the fuel. For a hydrocarbon fuel this is approximately three and a half times the weight of fuel and so the overall consumption must go up to at least four and a half times that of the equivalent air-swallowing engine. The second reason for high consumption is the inherently high jet velocity of the rocket. For a given available kinetic energy of the exhaust gas the thrust produced varies inversely with the jet velocity, which is almost four times as great as that of the turbo-jet engine. Combining these two factors gives consumptions of nearly eighteen times the turbo-jet figure and the question arises whether anything can be done to reduce this ratio.

An examination of the parameters will reveal the answer, but first t should be noted that it is

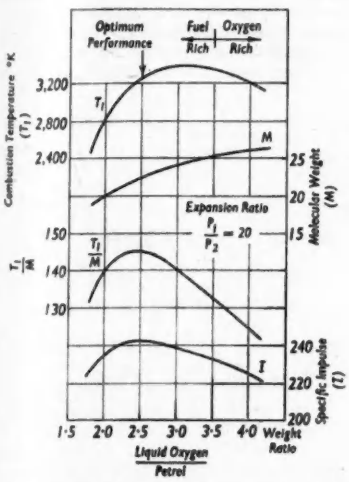


Fig. 1—Effect of mixture ratio on rocket propellant performance

more usual with rockets to consider specific impulse, which is the inverse of specific consumption. It is defined as the thrust produced with unit rate of propellant consumption and it can be written as

$$I=\frac{3600}{q}=\frac{v}{g}=\sqrt{\eta\cdot\frac{2}{g}\cdot\frac{\gamma}{\gamma-1}\cdot\frac{KT_1}{M}\cdot\left(1-\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right)} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In practical motors I lies between 200 lb and 250 lb per second and improvements depend upon improving the parameters in the foregoing expression. T_1, M and γ are functions of the propellants used and their mixture ratio while the ratio P_1/P_2 is set by the designer. It is usually of the order of 20 : 1 or 30 : 1 and is the main factor determining the thermal efficiency. The more it is raised the better the specific impulse becomes, but the rate of improvement falls off rapidly above 20 : 1 and even an infinite pressure ratio would only raise it by 50 per cent. Also the gains must be balanced against the disadvantages of increased nozzle weight, which will be referred to later.

The other possibilities for improvements appear on first sight to be an increase in gas temperature T_1 and a decrease in gas molecular weight M. These two factors are not, however, independent and the objective must be to make T_1/M an optimum. The variation of these parameters for a liquid/oxygen petrol propellant combination is shown against mixture ratio in Fig. 1. Because of dissociation the maximum gas temperature does not occur at stoichiometric mixture, but at some 10 per cent fuel rich, beyond which it decreases slowly. Similarly, the molecular weight of the gas tends to fall with rich mixtures, but more rapidly, and the combined effect is to give a maximum of T_1/M at almost 40 per cent rich. This is repeated in the specific impulse curve, although the gas temperature has fallen from 3400 deg. K. to 3280 deg. K. While this reduction in temperature is a fortunate accident for the designer who has to combat its effects on the combustion chamber walls, it still leaves it at values much higher than those found in any other internal combustion engine and the heat transfer problem is formidable. Thus, even if propellants with higher gas temperatures are available, they may have to wait for improved cooling techniques before they can be used.

A more attractive alternative is the reduction of molecular weight and this implies a fuel rich in hydrogen. Hydrazine (N_2H_4) and ammonia (NH_3) are good examples, but another consideration must enter at this stage. Not only must a high specific impulse per unit weight of propellant be achieved, but equally important is a high specific impulse per unit volume. The importance of this can be seen by the simple example given in Table I of the combustion of

TABLE I—*Performance of Liquid Oxygen and Liquid Hydrogen*

Mixture	Stoichiometric	100% Fuel rich
Oxygen/hydrogen by weight	8 : 1	4 : 1
Combustion temperature, T_1 deg. K. ...	3525	3025
Gas molecular weight, M	15·5	9·8
T_1/M	227	309
Specific impulse, lb/lb/sec	306	353
Propellant mixture density, lb/cu ft ...	25·5	17·6
Specific impulse, lb/gall/sec	1250	1000

liquid oxygen and liquid hydrogen.

This shows that the fuel rich mixture has 15 per cent advantage in performance on a weight basis, but is 20 per cent worse on a volume basis. For both mixtures the weight specific impulse is much greater than for the average propellants, but the low density of liquid hydrogen results in a poor volume specific impulse. By comparison, the liquid oxygen/petrol impulse is approximately 2370 lb per gallon per second, nitric acid/hydrocarbon 2780 lb per gallon per second, and 85 per cent hydrogen peroxide/hydrocarbon 2760 lb per gallon per second.

The three oxidants mentioned are those in most common use, and much controversy has raged round their respective merits and faults. Cleaver† discussed them in detail and there is little to add to his review, except to note that on a volume basis nitric acid and hydrogen peroxide are practically equal, but the latter has a combustion temperature of only 2600 deg. K., compared with 2950 deg. K. for nitric acid and nearly 3300 deg. K. for liquid oxygen. For this reason alone, hydrogen peroxide must be very attractive to rocket motor designers and when coupled with its ability to provide energy directly for driving the turbo pumps and accessories it becomes, in the author's view, pre-eminent.

The remaining factor in the specific impulse equation is the efficiency η with which the propellant chemical energy is converted into gas kinetic energy. It corrects the theoretical impulse to practical values, taking into account combustion efficiency, heat transfer losses, imperfect gases, friction losses and other expansion nozzle losses. These can account for some 5–10 per cent reduction in impulse and any improvement must be mainly a matter of improved mechanical design.

It can now be seen that the answer to the question of improving specific consumption is that the prospects are not very bright for any major reduction, but a number of minor reductions may be possible. These should not be neglected as they can give a more than proportionate improvement in performance. In a ballistic flight path, for example, the range varies as the square of the specific impulse, so that a 10 per cent improvement in impulse will give 21 per cent increase in range.

While the improvements to be expected by changing the propellants or modifying the motor design are limited, one further possibility exists. The use of an air augmentor duct surrounding the rocket jet would give an increase in thrust due to the interchange of rocket jet kinetic energy and momentum with those of air in the duct. Theoretically this increase depends upon the augmentor duct and rocket jet mass flow ratio. It falls to zero as forward speed/rocket jet velocity increases and then once more rises. As an example, for a typical arrangement with a mass ratio of 10 : 1, thrust increase would be 40 per cent at take-off, zero at 450 m.p.h. and 5 per cent at 1000 m.p.h. To achieve this, the entry to the air duct would have to be shaped as an accelerating or diffusing section according to the speed ratio. This is, of course, similar to the intake problem facing the turbo-jet and the ram-jet. Practically, the amount of augmentation depends upon the friction losses, mixing rates and entry efficiency. In some experiments with a small rocket motor, made at the College of Aeronautics, Cranfield, ducts with augmentor/rocket jet diameter ratios from 7 : 1 to 14 : 1 were tested statically, and thrust augmentation from 17 per cent to 40 per cent was actually measured. In all cases the optimum length/diameter ratio of the duct was between 5 and 7. Duct dimensions are important and too large a duct would be difficult to install, apart from the excessive friction and drag losses introduced. These are likely to be large in any case for high-speed flight and, as altitude increases, the air mass flow will be reduced and the proportionate thrust increase will be less. Thus the advantage of a simple augmenting device will mainly apply to the low

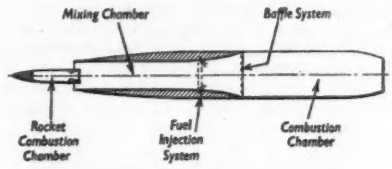


Fig. 2—Rocket-ram-jet duct combination

speed, low altitude range, that is, to take-off. For this purpose it need be only a light tube as pressures and temperatures will not be far removed from atmospheric. It can be easily jettisoned after take-off, either by itself or with the rocket motor.

The rocket/duct combination was studied by the Germans, not primarily to improve the rocket performance, but to assist ram-jets at low speeds. Fig. 2 shows one of the arrangements adopted. It was effectively a ducted rocket coupled to a ram-jet combustion chamber. With it ram-jet static thrust could be developed, although very inefficiently. Its chief merit was that the rocket jet was of decomposed hydrogen peroxide and the oxygen present enriched the ram-jet air supply.

Motor Weight.—It has already been indicated that the rocket motor is very light at sea level and, relative to other engines, much lighter as the altitude increases. Some actual weights are given in Table II. These show considerable

TABLE II—*Rocket Motor Weights*

Motor	Oxidant	Thrust, lb	Weight/thrust
"BMW.109–718"	HNO_3 ...	2,750 ...	0·065
"V.2"	LO_2 ...	60,000 ...	0·035
"A.S.M. Snarler"	LO_2 ...	2,000 ...	0·107
"RMI 6000-4c"	LO_2 ...	6,000 ...	0·035
"HWK.109–509"	H_2O_2 ...	3,750 ...	0·100

scatter in specific weight, but the general indication is that figures of 0·05 lb per pound or less should be possible at the present time. Actual figures will depend upon designed combustion pressure, as an increase in pressure will involve heavier gauge material in all pipes, control valves, pumps, and the combustion chamber itself.

The weight of the motor may be written as

$$W_m=a+b\,.\,E \quad . \quad . \quad . \quad . \quad (2)$$

and the weight of propellant

$$W_p=q\,.\,Et \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The relative overall weight for a motor operating at pressures P_1 and P_2 can then be written :

$$\frac{W_1}{W_2}=\frac{a+b_1E+q_1Et}{a+b_2E+q_2Et} \quad . \quad . \quad . \quad . \quad (4)$$

An analysis on these lines will give results of the form shown in Fig. 3. It might have been assumed that all the main components would increase in weight with increasing pressure, but actually the combustion chamber dimensions are reduced and its weight falls. Other advantages follow from this, but these will be discussed in a later section. The reduction is offset by the extra length of divergent nozzle necessary to obtain complete expansion of the gases, but the nozzle effect only begins to take charge at comparatively high pressures, say, 700 lb per square inch and above, assuming expansion to 14·7 lb per square inch. The result is that the total motor weight shows a shallow minimum near 300 lb per square inch combustion pressure

† "Rockets and Assisted Take-Off," *Journal R.Ae.S.*, 55, 1951.

(Fig. 3(*a*)). Against that, combustion chamber propellant consumption is continually reduced as pressure ratio increases, but consumption by the turbine driving the propellant pumps increases (Fig. 3(*b*)). The latter is a small fraction of the main consumption, being between 1½ per cent and 3½ per cent at 300 lb per square inch chamber pressure, depending upon the design efficiency. The rate of increase at high pressures will, however, more than balance the decrease of main consumption and the total consumption will tend to rise slowly. Finally, a combination of the fixed motor weight and the propellant weight which is variable with time will give an all-up weight at a fixed combustion pressure which can be plotted against operating time (Fig. 3(*c*)). By comparing various constant pressure conditions, the optimum can be found. It might be assumed that this would be at the pressure which gave the minimum total consumption rate as, by operating long enough, this would more than balance any extra motor weight. While this is true, the time at which an advantage would be realised would involve much greater quantities of propellant and longer operating

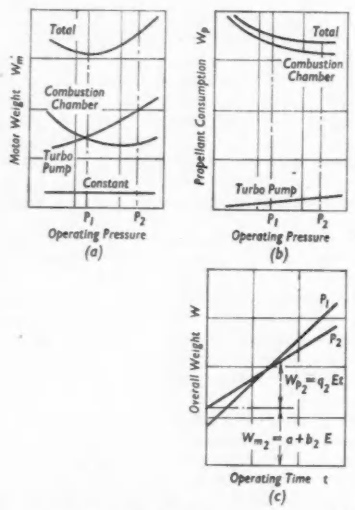


Fig. 3—Effect of combustion pressure on weight of motor and propellant

times than are normally possible. In practice, the advantages in going higher than 600 lb per square inch is small and other considerations tend to keep it lower.

If it is assumed, for example, that the motor will be used to boost the aircraft performance on climb, or in high-speed acceleration, it is unlikely to be used below 20,000ft. At this height the atmospheric pressure is less than half the sea level figure and consequently a combustion chamber pressure of 300 lb per square inch absolute which would give an expansion ratio P_1/P_2 of 20 : 1 at sea level, could give with a suitable nozzle more than 40 : 1 at 20,000ft, or 66 : 1 at 30,000ft. This would result in a motor weight W_m only slightly greater than the normal 20 : 1 design, but would give a propellant consumption W_p even better than indicated for the corresponding high-pressure design.

Combustion Chamber Design.—The combustion chamber consists of a burner head, combustion space and exhaust nozzle, and associated with it are an ignition system, a cooling system and a thrust control system.

Generally, the heat release from unit volume of combustion chamber is much greater than for the air-swallowing engines and even when measured as an intensity it is much superior. This is due, in part, to the high pressures and temperatures in the chamber which encourage high reaction rates and, in part, due to the burner head and chamber design which ensures good mixing of oxidant and fuel and the longest " time of stay " for reaction.

Many shapes and sizes of chamber have been tried and an equally large variety of propellant injectors. For a given chamber volume V_c, a spherical shape has the advantage of minimum surface area exposed for gas heat transfer and the strongest mechanical design. The German " 509 A.2 " chamber approached this shape, but involved some difficult production problems. At the other extreme, a long tubular chamber ensures that the propellant cannot pass through without a relatively long residence time. It gives a small cross section, but the gas velocity will be greater and the chamber wall surface will be large. These variations are shown diagram-

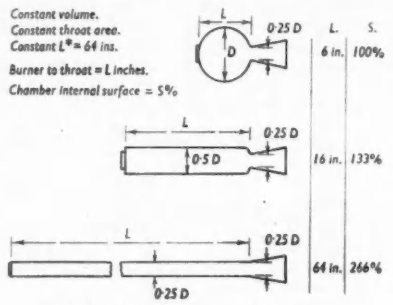


Fig. 4—Combustion chamber shapes

matically in Fig. 4, which gives two extreme examples and one intermediate. In all cases, the combustion volume is the same and the divergent nozzle is the same. It follows that the average time of stay is the same, and this can be conveniently described by the characteristic length L^* of the chambers. This is defined as

$$L^* = \frac{V_c}{A_t}.$$

In the third example, the so-called " throatless " chamber, the combustion space has the same diameter as the throat and so its length is L^*. Experiment has shown that normal combustion chambers are satisfactory when L^* is not less than 50in to 70in, depending upon the burner design and the propellants used. It has been found, however, that the throatless chambers can be run successfully at very much smaller L^* values (12in or less), and this suggests that the direct path length may have some influence, especially as the combustion efficiency of spherical chambers is not high unless L^* is large. If this is so, considerable reduction in conventional chamber size could be achieved.

The advantage of reducing L^* is that weight is reduced and this is shown by the curves in Fig. 5, which have the same form as in Fig. 3(*a*). In addition, the wall surface for heat transfer is less, but there is a fundamental loss in performance in small diameter tubular chambers, because the high gas velocity in the chamber entails a high pressure drop. It amounts to a loss of 21 per cent in thrust for the throatless, compared with the spherical chamber, with the same initial pressure, but rapidly falls as chamber/throat

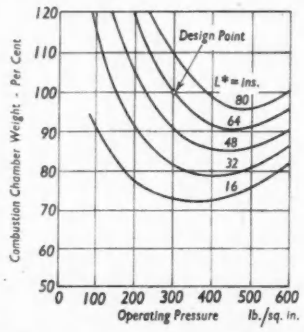


Fig. 5—Effect of L^* on combustion chamber weight

diameter ratio increases and it is only 1½ per cent for the intermediate chamber. In this case, the actual chamber length is assumed to be 16in and L^*=64in, but if the chamber length could be reduced to 12in, L^* would drop to 48in.

Other drawbacks of the throatless chamber are the small space available for the burner head and a tendency to unstable combustion when operating away from designed conditions. The latter is something akin to screech in turbo-jet reheat systems and just as destructive. It can occur in any combustion chamber if appropriate conditions exist. These are not well understood as yet, but are related to the chamber design, propellant injections and fuel feed system. Theoretical studies have been made by Crocco and others based on the assumption of a time lag between liquid injection and the development of gas pressure by combustion. In chambers of small characteristic length, this lag can represent a large proportion of the total time of stay and conditions are then particularly conducive to building up and maintaining large amplitude pressure fluctuations.

Burner Head.—The burner head usually consists of a number of propellant injectors and its duty is to ensure the intimate mixing of oxidant and fuel in correct proportions as rapidly as possible. This is the first of the complex series of processes which the propellants undergo. Almost simultaneously atomising, vaporising, mixing and partial combustion are proceeding, but knowledge of the best conditions and how to produce them is slight, as is witnessed by the widely different examples of burner shown in Fig. 6. One point which is fairly clear is the

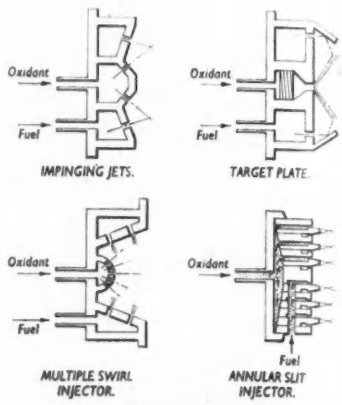


Fig. 6—Burner head arrangements

need to keep the axial velocity of the propellants low when injected. Reference has been made to the burner-to-throat distance and a high axial velocity would tend to reduce the effective length of this. The requirements for low injection velocities call for a relatively large injection area to deal with the high flow rates and this means that burner heads will have difficulty in matching the demand for small diameter chambers. It must also be remembered that the burner head has a load of 300 lb per square inch or more, according to the combustion pressure acting over its face and must not be seriously weakened by too many or too large injector holes.

Expansion Nozzle.—This component is almost of equal importance with the combustion chamber proper because its weight may be more than 50 per cent of the combined weights, and its efficiency decides how much of the gas pressure energy developed in the chamber is converted to kinetic energy. As frequently happens, the two factors are mutually opposed and a compromise is necessary. Practical nozzles are usually made as straight-sided, truncated cones to ease production, but a better theoretical contour can be found which gives a relatively short nozzle. If the conical nozzle is shortened by increasing its angle, there is an increasing thrust loss due to the radial component of the jet. This amounts to about 3 per cent when the cone angle is 40 deg., but greater divergence produces a rapidly increasing loss, as shown in Fig. 7. The figure also indicates how the nozzle relative weight decreases with increasing divergence and increases with increasing pressure ratio for a fixed combustion pressure. The advantages of designing for a high-pressure ratio and a low exhaust pressure has been mentioned already, but again the extra nozzle weight must be balanced against reduced specific consumption. This is not entirely dependent upon designed pressure ratio as the thrust will be increased for an under-expanded jet by an amount proportional to the excess pressure remaining in the jet and the exit area of the nozzle. The total will be less than that for a correctly expanded jet, but the loss is not serious within a reasonable range

of exhaust pressure either side of correct. This is shown in Fig. 8, where the specific impulse is plotted against altitude for correct expansion at all altitudes, at sea level only, and at 20,000ft only. In all cases, the combustion chamber pressure is fixed at 300 lb per square inch. The last case shows an inferior performance near ground level, but above 30,000ft is giving a considerable saving in consumption. For a

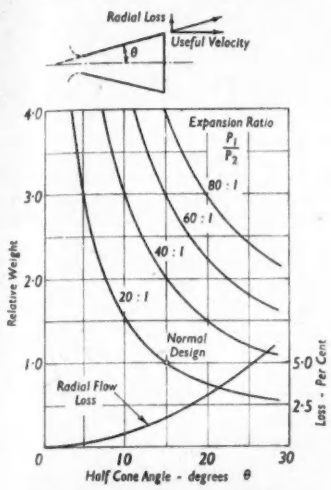


Fig. 7—Expansion nozzle design

motor of 5000 lb thrust it would amount to 0·75 lb per second at 50,000ft for a probable increase in nozzle weight of 15 lb.

Although this would appear to give a worthwhile improvement, it does involve a longer and larger diameter nozzle. This may not be a serious matter in an aircraft installation, but a real problem could be introduced in the cooling of the extra nozzle surface if the heat transfer were already critical.

Combustion Chamber Cooling.—No discussion on rocket motor problems would be complete without some reference to the heat transfer difficulties that beset the designer. The combustion chamber contains gas at very high tem-

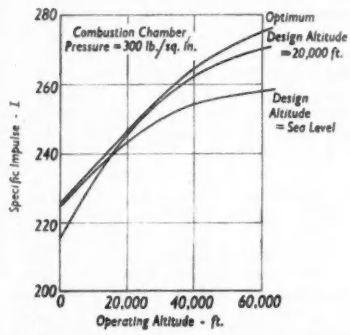


Fig. 8—Effect of expansion nozzle design on performance

peratures which is flowing at high velocities. These conditions produce high rates of heat transfer to the chamber walls and it is essential for the walls to get rid of the heat picked up just as rapidly, or else their temperature will rise to the point of failure. The usual method of doing this is to transfer the heat to the liquid propellant which flows in a jacket surrounding the chamber before being injected through the burner head. This has the advantage that very little heat is actually lost, as the flow out of the chamber is absorbed by the propellant and then returned to the combustion space. Because of this, it is important that the total heat transferred should not be more than the propellant is capable of absorbing without boiling. The total quantity will depend upon the surface area exposed to the gases and this should be kept to a minimum. In relation to the thrust, surface area increases as the thrust decreases and a point will be reached where regenerative cooling cannot be maintained. In present-day motors this is at a relatively low thrust, but if combustion temperatures are raised, so will be the minimum size of chamber. For a given thrust, spherical chambers have the least exposed surface and for all chambers the area is reduced by operating at higher pressures.

The wall temperature on the gas side reaches values approaching 1000 deg. Cent. at the nozzle throat. This is very close to the limit of the material strength so that for higher gas temperatures some improvements are necessary. As the temperatures depend largely upon the convective heat transfer coefficients between the gas and wall and between wall and liquid, modifications to these coefficients would be one line of attack on the problem.

A small coefficient is required between the gas and wall in order to produce a steep temperature gradient across the boundary layer. There is little that can be done here except to introduce an artificial boundary layer of cool gas. This can be done by allowing a liquid film to flow on to the chamber wall. The liquid vaporises and its latent heat helps to keep the wall temperature down. The vapour will continue to keep the temperature low for a short distance downstream, but it will be quickly absorbed into the turbulent boundary layer and then becomes ineffective. Some method of avoiding this and injecting only boundary layer quantities could provide a big advance in rocket performance. At the moment, application of this film cooling technique is expensive in liquid consumption, as a fresh injection must be made at intervals through the chamber and each injection puts in many times the theoretical amount required. Consequently, as in early turbine blade cooling tests, the gain in performance is offset by the additional coolant expended.

On the other side of the chamber wall, the effort is towards obtaining a high heat transfer and this demands a high velocity of the coolant. This means a small radial passage width and a high pressure drop through the jacket. The latter is objectionable because of the extra pumping power required, but more so because the propellant must be at a higher pressure than the gases inside and hence the chamber is subjected to a collapsing load. This can be resisted by increasing the wall thickness, but this increases the resistance to heat flow and puts up the wall temperature on the gas side. The effect of wall thickness and passage width at a typical chamber section is shown in Fig. 9.

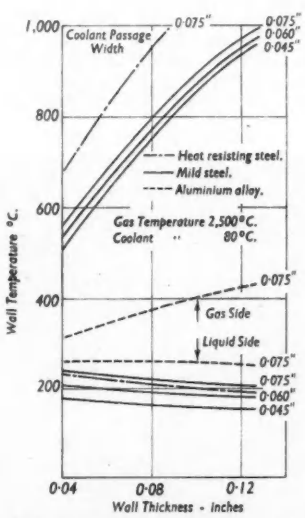


Fig. 9—Effect of combustion chamber wall thickness, material, and coolant gap on temperature

Apart from the high pressure drop in the jacket, small coolant passage width presents a practical problem of assembling and holding the gap exactly right.

One method of improving the heat transfer on the liquid side is by nucleate boiling. A large increase in heat transfer can occur without much rise in temperature if the liquid boundary layer boils and forms small bubbles which are swept off the wall into the main mass of the coolant. It is a difficult condition to design for and the danger is that the bubbles may coalesce and prevent liquid from reaching the wall. In this case failure would follow very rapidly. Probably very few chambers have been designed for nucleate boiling heat transfer up to the present, but it may have occurred quite fortuitously in very many others. When it can be properly controlled it will assist the designer to improve the motor performance materially. If, for example, the heat conductance of the liquid film could be doubled, the wall temperature on the gas side at the throat could be dropped by about 80 deg. Cent. or, alternatively, keeping the inside wall temperature the same, the gas temperature could be raised from 2500 deg. to 2750 deg. Cent. The same effect is obtained if the physical properties of the coolant are suitable. Water is one of the best coolants available, having a conductance twice as good as methanol and four and a half times better than kerosene at atmospheric temperature. In all cases, the conductance improves with increasing temperature and for kerosene is about 1·6 times as great at 100 deg., as at 20 deg. Cent. and for water, about 2·0.

The material of the wall influences temperature in the same way, a high conductivity giving a lower temperature if other conditions remain the same. This is also shown in Fig. 9, which includes curves for an aluminium alloy, heat resisting steel, and mild steel. Aluminium has a much lower temperature than the steels but, unfortunately, its specific strength (proof stress/density) is negligible at the temperatures required. Copper is even better than aluminium in easing heat transfer and wall thickness is not a major problem, but again its strength is low and it is susceptible to oxidation and erosion on the gas side. At the other end of the scale, heat resisting steels have the highest specific strengths at high temperatures, but their poorer conductivity causes higher wall temperatures which counterbalance the better strength. On the whole, therefore, mild steel proves to be as good a material as any.

Technical Reports

Measurement of Pressure with the Mercury Barometer. National Physical Laboratory. Notes on Applied Science No. 9. London: H.M.S.O., York House, Kingsway, W.C.2. Published for D.S.I.R. Price 1s.—" Measurement of Pressure with the Mercury Barometer " is the ninth of a series of publications issued by N.P.L. with the object of providing industry with information on various technical and scientific subjects not readily available elsewhere. The booklet is concerned with the measurement of gas pressures by means of mercury columns, within the range 0 to 1200mb, to an accuracy of $\pm 0 \cdot 1$mb. If greater accuracy is required, the advice of the Metrology Division of N.P.L. should be obtained. The first section of the book deals with fundamentals, including definitions of the units of barometric pressure which have been internationally agreed on with effect from January 1, 1955. Apart from the dyne per square centimetre, the only units now internationally recognised are in order of preference, the millibar (1mb=1000 dyne/cm²), the millimetre of mercury at 0 deg. Cent. and standard gravity, and the inch of mercury under the same conditions. This part is followed by descriptions of the Fortin and the Kew type of barometer, their use, transport and storage. The correction of readings is discussed and a worked example given. In conclusion there is a brief account of the testing procedures carried out at the N.P.L.

Oriented Polystyrene Film Capacitors. A Major Cause of Premature Breakdown (Ref. L/T289). By H. F. Church. The British Electrical and Allied Industries Research Association, Dorking Road, Leatherhead, Surrey. Price 7s. 6d., postage 3d.—Difficulties have been encountered in the industrial production of polystyrene film capacitors because of the very high rejection rate on heat treatment of the units, an essential part of the manufacturing process. It has been shown that the main cause of failure is the inadvertent introduction by the machine operators of occasional particles of greasy material, the grease having a plasticising action on the film during the heat treatment and causing holes to be formed in the neighbourhood of the particles by local relaxation of the oriented polystyrene film. The commonest source of harmful particles is dandruff from the scalp, which is impregnated with natural body oils. Ordinary dust appears to be relatively harmless. Precautions in manufacture to avoid this trouble are suggested.

Restoration of the Saugus Ironworks in Massachusetts

BY OUR AMERICAN EDITOR

ONE of America's earliest industrial landmarks, the country's first successful ironworks, has now been completely and authentically restored at Saugus, Massachusetts, 10 miles north of Boston, and was opened as an "outdoor museum" recently. The colonial ironworks, which dates back to 1646, was rebuilt at a cost of over a million dollars contributed by the American iron and steel industry. All of the major units of the seventeenth century ironworks have been rebuilt, including the blast furnace, the forge, the rolling and slitting mill, the wharf and a warehouse for storing completed products. Also on the museum site is the Ironmaster's House which was restored about 1915.

Although some iron had been made earlier at several points in what are now the United States and Canada, the Saugus ironworks can claim the first successful and sustained production of cast and wrought iron in North America. A completely integrated ironworks, the Saugus plant was a large-scale enterprise for its day. The works was created three centuries ago principally through the efforts of John Winthrop, Jr., the son of the founder of Boston, and Richard Leader, a merchant of Salehurst, England. Winthrop promoted the plan to develop New England's iron resources while Leader actually established the works. To finance the scheme, a group known as the "Company of Undertakers for the Iron Workes in New England," was organised in London. The investors, who were either Englishmen or residents of the Massachusetts Bay colony, included merchants, ironmasters, lawyers, brewers, civil servants, merchant tailors, a physician and several clergymen, and the starting capital was £1000 sterling. Later investments brought the total to about £15,000 and it is believed that the company was the first large-scale capitalistic enterprise of its kind in the American colonies. The site selected for the ironworks had a number of natural advantages. Saugus was half-way between Boston and Salem, the two largest settlements in Massachusetts. Nearby were ample supplies of bog iron ore, extensive woodlands to supply charcoal, a natural elevation to facilitate charging the furnace from the top, and a navigable stream which could be dammed to provide the necessary water power.

The ironworks, although built in the wilderness of the Massachusetts Bay colony, utilised the most advanced methods of iron-making then known. The blast furnace, which operated about thirty weeks of the year, produced about a ton of cast iron a day. The rolling and slitting mill was one of the few existing in the world at that time. From the metal smelted in the blast furnace, workmen produced cast iron objects such as pots and firebacks and crude iron pigs. The pigs were carried to the forge, where they were reheated, converted into wrought iron and beaten into bars under a large water-power driven hammer as shown in the accompanying illustration (Fig. 1). Some of the bars made at the forge went to the rolling and slitting mill and were worked into flats and rods. From these rods, the local farmers made their own nails, a product in great demand in the growing colony. Many finished products were sold right at the site. Some were hauled by boat or by cart to meet the needs of smiths and merchants in nearby towns, and others were shipped to a central warehouse in Boston for local sales or shipment overseas.

In addition to turning out a good grade of iron, the Saugus works provided a training ground for skilled workers in this vitally needed industry. From Saugus, ironmen and masters migrated throughout New England and down the Atlantic seaboard, and as a result new ironworks sprang up at Concord, Rowley, Taunton, New Haven and Providence. In the meantime, however, Saugus ran into difficulties. There was mismanagement by several of the ironmasters. The supply of raw materials began to run out. The new ironworks was unable to meet the competition of imported iron. The managers found themselves in conflicts with local authorities, and it became increasingly difficult to hold skilled ironworkers in a new settlement where farm land was cheap. Thus, after years of dwindling operation, the Saugus ironworks was abandoned about 1670 and fell into ruins.

The ancient site, overgrown with brambles, might have remained obscure except for the loyalty of a group of New Englanders led by Miss M. Louise Hawkes, whose ancestors lived in Saugus as far back as 1630. In 1941, graduates of the Ford Trade School bought the old Ironmaster's House, intending to move it to Greenfield Village, at Dearborn, Michigan, as a gift to the late Henry Ford. Miss Hawkes was familiar with local traditions revolving around the ironworks and believed that what originated in New England should remain there. She carried her fight to keep the house in Saugus to Governor Saltonstall, of Massachusetts, and, finally, with the co-operation of Henry Ford himself, the structure was allowed to remain in New England. The First Iron Works Association was formed in 1943 to carry on the work of focusing public attention on the site. A few years later Quincy Bent, a retired steel works executive, attended one of the meetings. Recognising the ironworks as Americana of prime significance, he discussed the project with officers of the Association. As a result of this meeting, he passed on to the Board of Directors of the American Iron and Steel Institute what was then known about America's first successful ironworks. After studying the information the Institute's Board assured financial support for the restoration work.

During the excavation of the old ironworks, over 5 tons of artifacts were taken from the ruins. They ranged from tiny brass pins to a 505 lb iron hammer-head used in the original forge building. These, together with recovered iron pots and pans, knives, axes, saws, shovels, scissors, pieces of leather shoes and broken pottery, are providing a wider knowledge of life in the American colonies three centuries ago. One of the most important finds was a water wheel, 16ft in diameter, which furnished power for the bellows of the blast furnace. Covered with moist earth, which undoubtedly preserved the old oak and pine boards, the remains of the wheel were discovered in 1951. They were lying 21ft below the surface of a main street, less than 10ft from the stone furnace. When the wheel had been found it had to be removed and measured so that a workable

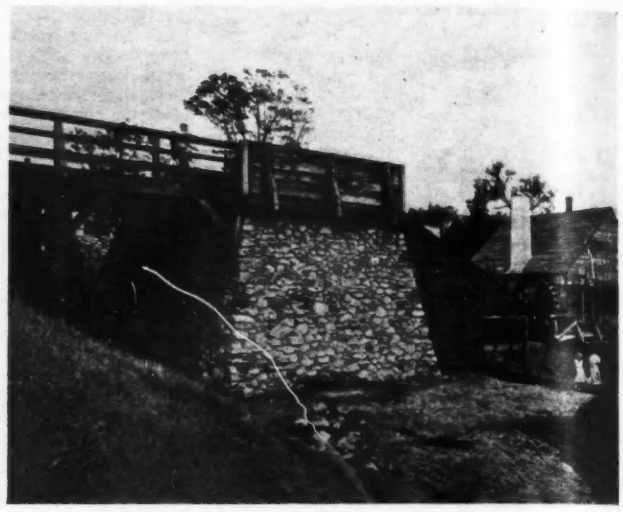


Fig. 2—Reconstructed blast furnace at the Saugus Ironworks

Fig. 1—Beating of wrought iron bar under the forge hammer at the Saugus Ironworks

replica could be made. Once taken from its mud bath the wheel began to crumble and disintegrate. Experts from Harvard University were called upon and developed an unusual preserving process. Sections of the wheel were carefully removed, wrapped in water-soaked burlap and rushed to the Harvard laboratories, where they were placed in large vats of melted paraffin wax. During a three-hour heat treatment the water in the wood vaporised and was replaced by the wax. The wax was allowed to cool and harden, leaving the treated sections almost as solid as the day they were made.

The drawing reproduced in Fig. 3 shows the reconstructed 21ft high blast furnace at the Saugus site. The external structure comprises a squat pile of stone, partly wrapped with a wooden shed to shelter the casting operations and the bellows and their gear, topped by a wooden wind screen and joined to the adjacent bank by a massive charging bridge. In terms of construction the unit is a stone structure about 26ft square at the base, 21ft high and with outer walls sloping inward as they rise. Made of granite and other local stones bonded with a clay mortar, it rests on level ground and is equipped with a subterranean drainage system to guard against the dampness to which the water that turns its huge bellows wheel makes it peculiarly susceptible. In the interior is a stack 6ft in diameter at its widest point, and below the boshes is a square crucible which, like the lining of the whole cavity, is made of refractory sandstone. Between the lining and the outer walls are one full inner wall and another which runs up to and helps support the boshes, the space between lining and inner and outer walls being filled with sand, clay and rubble. In two of the outer walls are large and deep arches. Through the smaller one pass the noses of the bellows and the tuyere through which their blast is delivered to the crucible. Under the larger one is the working area of hearth and casting floor.

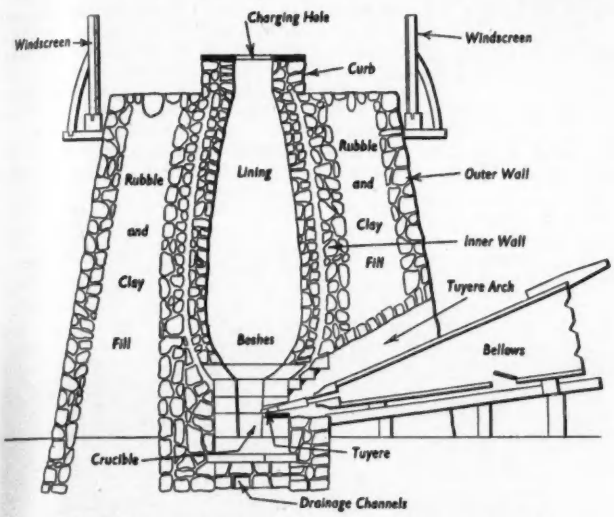


Fig. 3—Cross-section of blast furnace at the Saugus Ironworks

It is not easy to estimate the output of the original Saugus furnace with precision. The lower portion of the crucible and the forehearth had a combined capacity of about 5 cubic feet, sufficient, if all space were utilised and all slag removed, to hold about a ton of liquid iron. In actual practice, however, the furnace yield came in much smaller quantities. The average pig was only about 3ft long. The largest uncovered in the excavations is only 52in long and weighs but 290 lb. There is a documentary reference to one pig of about 500 lb, indicated as the product of twenty-four hours of furnace activity. This was apparently the maximum yield for a single tapping. In terms of totals the picture is also less than perfectly clear. Governor Winthrop once cited 8 tons per week as the furnace yield. This rate may have been reached, but it was not sustained for any extended period.

Our final illustration shows the reconstructed rolling and slitting mill with its large cog and lantern wheels. The work of the archeologist at Saugus has made it clear that this slitting mill had but a single watercourse, and a wheelpit that accommodated two 17ft wheels. This could only mean the use of indirect power transmission. Thus, it was assumed that one wheel drove one shaft directly, providing the power for the bottom set of rollers and cutters. On the shaft of the other waterwheel, however, was a cogwheel which engaged a lantern pinion. Energy transmitted to the latter, which was carried on a shaft above and parallel to that of the first wheel, caused the upper set of rollers and cutters to revolve in the appropriate direction and at proper speed. As in the simpler or directly powered mills of the period, the working units, the pair of rollers and the pair of slitters, stood side by side and were joined by couplings. A shears operated by a cam on one of the waterwheel shafts was also a part of the machinery. The work of this mill consisted of heating bar iron, rolling and slitting it, and straightening and bundling the finished products, flats and rods.

Bar iron, the product of the "finery" and "chafery" forges, normally about 3in wide and 1¼in thick, was cut cold into 2ft or 3ft lengths in the shears. The pieces then went into the heating chamber of a small, crude, wood-fired reverbatory furnace. The heating took three to four hours. Then the pieces of iron were taken out one at a time and passed through the iron rolls, which drew them out, probably in two or more passes, to a length of 8ft or 10ft. At this stage the iron was about 5in wide and about ¼in thick. Most of this rolled iron or flats next went through the slitting unit, where it was cut lengthwise by from three to six forged discs, depending on the width desired for the finished rods. A stream of running water, tapped from the waterwheel flumes, trickled down on both rollers and cutters as the iron was passing through them. The rods were next cleaned and straightened on the racking table and then bound in bundles with metal straps that had been heated in a small charcoal-fired hearth. It is known that many later mills also had a small blacksmith's forge conveniently situated for the maintenance and repair of the rolls and cutters, which took rough treatment from what was obviously a heavy duty operation. It is not yet clear whether this was the case at Saugus.

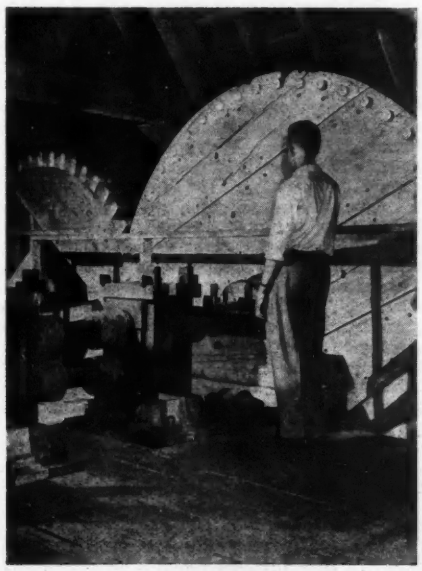


Fig. 4—Reconstructed rolling and slitting mill at the Saugus Ironworks

Fragmentary surviving data provide an approximate picture of production at the slitting mill. No more than one-eighth of the bar iron produced in the forge went through the rolling and slitting processes. Rod iron brought a higher price than bar iron, £28 a ton as against £20 a ton, but production costs were also higher, of course. Besides the expenditures for the labour, fuel and upkeep involved in taking iron through additional stages of production there was a weight loss. Between the end of January and December 5, 1652, for example, 23 tons, 3 cwt, 1 qr and 24 lb of bar iron were delivered to the slitting mill. From it was made 21 tons, 12 cwt of rod iron. The "Losse in Slitteing ye Ironn," as it is listed in the company accounts, was 11 cwt, 1qr and 24 lb. This was a year when rod iron production was good; average annual production for those years for which data exist came to no more than 12 tons, a puny total that indicates long mill shut-downs and many a headache for management and workers as well. Set against the production figures of the later American iron industry such figures are almost incredibly small. They are low for even these earlier days. Measured against the capital investment embodied in a building of considerable size housing heavy and rather complicated machinery, rod iron production seems to have been almost pitiful. Thus, the reconstruction of the slitting mill at Saugus stands more in testimony to the willingness to try of the men of America's first successful ironworks than as a tribute to great accomplishments. Nevertheless, it is felt that in no other part of the old ironworks now reconstructed at Saugus was there better evidence of the pioneering spirit which has been such a driving force in making American industry what it is to-day.

Westinghouse Gas Turbine for Spain

THE first Westinghouse gas turbine power plant destined for a country outside the Western Hemisphere has been ordered by Manufacturas Metalicas Madrilenas S.A., the large Spanish manufacturers of iron, steel and aluminium products. The 5MW gas turbine plant is intended to ensure a year-round supply of electrical energy for the company's mills despite prolonged dry spells which affect the electrical output from the country's hydro-electric generating units. Besides its advantage due to economical use of water, the gas turbine was selected over other types of prime movers because of its compactness and low initial and operating costs. The weight of the set will be 118,000 lb or about half that of a comparable steam-electric generating plant. The gas turbine installation will consist of three main components—an axial-flow compressor, a combustion system and a gas turbine with five stages of high-temperature alloy blading. A reduction gear will connect the unit with a 6250kVA generator. The gas turbine is being built at the works of the Westinghouse Electric Corporation in South Philadelphia, Pennsylvania.

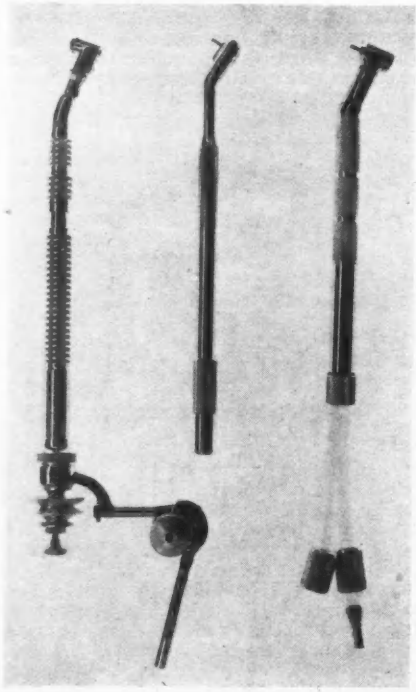
Production of Direct-Extruded Aluminium-Sheathed Cables

THE construction of the first extrusion press for the production of aluminium-sheathed cables in America is scheduled to be completed by the Schloemann Company, of Düsseldorf, this month. The press will be delivered in the summer and installed at the Perth Amboy Works of the General Cable Corporation in New Jersey. It will produce commercially the first direct-extruded aluminium-sheathed cables in the U.S.A. The process used in producing the aluminium sheathing is fundamentally similar to the "Al-Sheath" method jointly developed recently by British Insulated Callender's Cables, Ltd., and the Loewy Engineering Company in the United Kingdom (THE ENGINEER, June 11, 1954).

Turbine-Driven High-Speed Dental Handpiece

A PROGRAMME of dental research being conducted at the National Bureau of Standards, Washington, D.C., has resulted in the development of a hydraulic turbine dental handpiece which attains a speed of 61,000 r.p.m. At this speed, very low cutting pressure is required and dental enamel can be cut rapidly with a minimum of vibration and heating. By positioning the turbine in the head of the handpiece and connecting it directly to the cutting tool, the mechanical difficulties involved in the use of high-rotational speeds with the conventional belt-and-gear propelled cutting tools have been eliminated. Besides making possible more efficient cutting of tooth structures and reducing the time spent by the patient in the dental chair, the hydraulic turbine handpiece also promises to be of considerable utility in other fields where small amounts of hard materials must be removed by grinding, as in tool and die making.

At present the maximum speed of conventional dental cutting instruments is about 6500 r.p.m. Because of the small size of dental burrs, this rate of rotation gives too low a linear speed for efficient cutting of tooth structures. It has been found that a steel burr can remove the same amount of material in four seconds at 12,000 r.p.m. as it can in approximately thirty seconds at 2000 r.p.m. However, in spite of the disadvantages of using low rotational speeds, dentists have hesitated to use higher speeds with the conventional handpiece because of the excessive vibration and heat developed and the potential hazard to the patient caused by the high inertia of the revolving instrument. Several designs of dental rotary cutting instruments using air or water as the motive power have been constructed in the past, but each of these was designed for the straight dental handpiece, and each required that a gear-type contra-angle handpiece be attached. The instrument which has now been developed at the N.B.S. is designed to eliminate all gears within the handpiece, since the turbine is placed in the head of the contra-angle. This makes it possible to overcome many of the disadvantages of high rotary speed in cavity preparation by taking advantage of the smoothness and other characteristics inherent in hydraulic systems. Thus, vibration is minimised and the high-speed stream of fluid passing over the turbine and shaft acts as a coolant so that overheating is prevented in spite of the high rotational speed developed. A further advantage of the hydraulic handpiece is that even while rotating at top speed, the cutting instrument can be stopped immediately by placing a finger abruptly against its edge. Then, as soon as the disc is released, it will start rotating again. This means that if the operator should press too heavily on the cutting tool or if the tool should happen to catch or bind in some manner that would be hazardous with the ordinary handpiece, the hydraulic instrument will automatically stop rotating. Because of the extremely light pressures used for cutting, there is considerably less strain on the operator. Furthermore, the cutting tools do not climb or roll out of the cavity as do those used in the slower-rotating instruments. While some adjustment in the dentist's operating procedure is necessary, the dentist requires no special training in the use of the new handpiece.



Comparative size and appearance of hydraulic turbine dental handpiece (centre and right) and conventional belt and gear-driven dental handpiece (left)

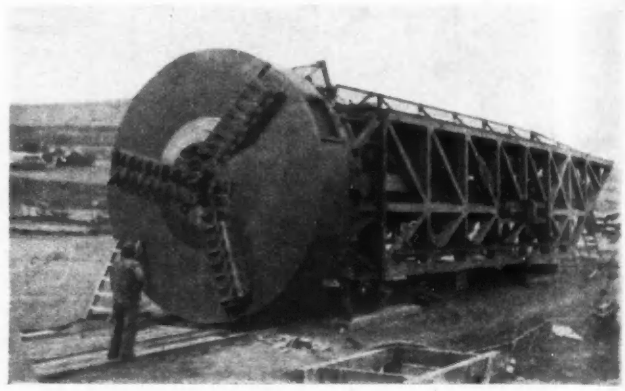
The overall size and shape of this handpiece are within the general proportions of the conventional gear-driven contra-angle handpiece, as shown in the accompanying comparative illustration. The turbine shaft is designed so that the hollow shaft of the cutting instrument fits over it. A spring key attachment on the turbine shaft fits into a keyway in the cutting-instrument shaft, and the centrifugal force developed by the rotating turbine causes this spring to lock the cutting instrument in place. When the shaft is standing still, the cutting instrument can be easily attached or removed. The turbine has six notched blades fixed to the shaft and measures 7·5mm in diameter by 4·8mm in length. Although steel ball bearings have been used in some models, they have proved rather harsh and noisy in this application. Various combinations of low-friction plastics materials in bearings and journals have proved much more satisfactory as they are quieter in operation and do not require lubrication. The hydraulic system associated with the turbine consists of a mobile cabinet which contains a fluid pumping mechanism, a reservoir tank, a pressure switch, a solenoid valve and distribution lines. The contra-angle handpiece is connected to a flexible coaxial double tubing. The $\frac{3}{16}$in diameter inside tube carries the water under pressure to the contra-angle handpiece, while the $\frac{5}{16}$in diameter outer tube carries the spent fluid back to the reservoir. The tubes join with the direct line from the pump and the line to the reservoir tank. A constant-volume pump, which is coupled to a $\frac{1}{2}$ h.p. electric motor, is used. To minimise undesirable motor noise, the pumping equipment is enclosed in a sound-insulated cabinet. The unit is self-contained and needs only to be connected to an electrical supply for operation. The fluid is stored in the reservoir and is used over and over; hence, the unit requires no adjustment during normal use. To stop the turbine momentarily the operator steps on a special tube containing fluid. The force exerted closes a pressure switch, thus opening a solenoid valve which allows the propellant to by-pass the turbine and to return directly to the reservoir. While the instrument is being used, the motor and pump operate continuously and the handpiece is energised as needed by the operator. Grinding tools such as points and discs of diamond and silicon carbide have been found to cut with exceptional efficiency when used with the hydraulic handpiece.

However, milling cutters like the steel and carbide burrs of current design do not function well at such extremely rapid rates of cutting. It is believed that the design of the cutting blades of all burrs will have to be modified before they can be used at the rotational speeds of this handpiece.

Tunnelling Machine at the Oahe Dam

AN unusual tunnelling machine weighing about 100 tons is being used to gouge out six long tunnels at the Oahe dam, which is being constructed by the U.S. Army Corps of Engineers, near Pierre, South Dakota. The flood control and power generating scheme is part of the Missouri River flood control programme. The machine is believed to be the first application of "continuous mining" methods to a large-scale tunnelling operation. The Oahe project, which will be completed in 1961, requires 8 miles of tunnels. Using conventional method of blasting and hand-mucking, tunnelling proceeds at a rate of 1ft to 2ft an hour. The new method is expected to give a rate of 6ft to 8ft an hour.

The finished diameter of the tunnels being constructed is 19ft 9in. The rough bore of each tunnel is 26ft 3in for the first 120ft and 24ft 9in for the remainder. The face of the machine comprises an inner cutter head 19ft in diameter and an outer cutter head having a diameter equal to the rough bore. The cutter heads rotate in opposite directions, the inner one at 9 r.p.m. and the outer one at 6 r.p.m. On the inner cutter head are mounted three radial rows of cutters consisting of fixed cutters spaced 10in apart and projecting 9in, followed by bevelled disc cutters spaced between the fixed cutters to break out material between the kerfs cut by the fixed cutters. The outer cutter consists of six buckets holding fixed and disc cutters arranged in the same order as those on the inner cutter head. The cutter heads are powered by two 200 h.p. electric motors. The buckets pick up broken material from the invert and drop it on to a 30in conveyor belt which travels with the machine. Material is transferred to a 24in conveyor and transported to the portal, where it is loaded directly into rubber-tyred haulage cars for removal to the disposal area. The machine is supported at the front by a shoe sliding on the excavated invert and at the centre of the jumbo frame on rails that are moved ahead as the machine advances. The machine is propelled by a hydraulic jack on each side pushing against the tunnel supports and the side of the tunnel excavation. The pusher arms are retracted and reset when the machine has advanced 4ft. Vertical control is accomplished by means of two hydraulic jacks mounted on the sliding shoe. Horizontal control is by a hydraulic jack on each side mounted just behind the cutter head. An overhead steel canopy and wooden siding cover the whole machine, with the exception of the cutting heads, thus affording protection to workmen in the tunnel from fallen debris.



Continuous tunnelling machine at the Oahe dam in South Dakota

Because the machine cannot travel backwards, it will have to be disassembled and brought out when the tunnelling operation is completed. The machine was constructed at a cost of more than 300,000 dollars for Mittry Constructors, of Los Angeles, California, the firm handling the tunnelling contract at Oahe for the Army Corps of Engineers.

Industrial and Labour Notes

Overseas Trade

In a speech which he made at Manchester last Friday evening, the Chancellor of the Exchequer, Mr. R. A. Butler, stated that the value of United Kingdom exports in January was £248,700,000. That was £7,000,000 below the exceptionally high figure reached in December and there was one more working day in January than in December.

The Board of Trade says that the export figures for January probably again include some shipments delayed by the dock strike. In the four months October to January, that is since the month the strike occurred, the average value of exports was £228,700,000, or £700,000 a month more than in the corresponding period a year earlier. For the first nine months of 1954 there had been an increase of 6 per cent over the corresponding period of 1953.

Re-exports in January were valued at £10,500,000. The value of imports into the United Kingdom in January has been put at £332,600,000, making the monthly average in the October to January period £300,000,000, which was 8 per cent higher than in the comparable period a year earlier. The excess of imports over total exports in January was £73,500,000. In the four months October to January, the average excess was £62,900,000 a month, compared with £39,200,000 a year earlier.

Industry and the National Economy

In the latest issue of *Bulletin for Industry*, the information division of the Treasury has surveyed the trends of British industry and the economy generally during last year. It says that, over the whole of 1954, industrial output seems likely to have been nearly 6 per cent higher than in 1953, although there was some slowing down in the rate of increase from 7 per cent in the first quarter to 4 per cent in the fourth quarter. The rise in production last year resulted mainly from higher output in metal goods, oil refining, paper, chemicals and vehicles.

The survey notes that the growth in output last year increased the demand for coal, steel, electricity and imported materials. Coal output failed to rise as much as had been hoped and imports had to be brought in; steel output established a new record, but it is pointed out that here also extra imports have recently become necessary. Increased output of vehicles and other engineering products, and greater output in the building industry, led to some difficulty in meeting the demand for certain kinds of steel from home production. The scarce products included sheet, tinplate, joists and other heavy sections and, the *Bulletin* adds, the shortage of the first two is likely to be the most persistent. Imports of all basic materials taken together were lower by value in 1954 than in the preceding year, but they appeared from the second quarter to be rising above a year earlier. Imports of non-ferrous metals, chemicals, petroleum and pulp and paper all rose in 1954, in some instances sharply, to support the growth of output by the user industries.

The survey goes on to show that home demand was taking about three-quarters and exports about one-quarter of the rise in industrial output last year, the proportionate increase being rather larger for exports than for the home market. World trade expanded slightly in 1954, despite the recession in the U.S.A. The volume of United Kingdom exports was about 5 per cent up on 1953 and was the highest ever recorded. A fall in shipments to the dollar area was more than offset by increases to Western Europe and the overseas sterling area, though, towards the end of the year there were signs that exports to North America were no longer falling. According to the survey, costs and prices rose only slightly for most of the year, food prices rising most. Industrial profits and dividends announced during the year were at higher levels than in 1953. By the end of last year some materials prices were moving up and there were a number of wage claims awaiting settlement. The index of weekly wage rates was 4 to 5 per cent higher at the end of 1954 than a year earlier. The average for the year was also 4 to 5 per cent higher than for 1953, and was slightly less than the increase in output. In the fourth quarter of last year, however, the pace of advance in wage rates was maintained whilst production was rising less quickly.

The Treasury concludes its survey by saying that no firm conclusions can yet be drawn about industrial investment in 1954 or the likely trend in the current year. The statistics are incomplete, although the pointers they provide are encouraging. The factory building figures, for example, show big increases in approvals, starts and completions in the first half-year and approvals rose further in the third quarter of last year. Machine tool orders, which are a good guide to future investment in plant and machinery, have also been rising, and expansion programmes have been announced by a considerable number of firms. These indicators, the Treasury says, while providing no firm guide to the extent of investment in 1954, suggest that private investment has moved upward.

Future of the Steel Industry

On Thursday of last week the annual general meeting of The United Steel Companies, Ltd., was held, and in his chairman's statement, Sir Walter Benton Jones made some comments about the future of the iron and steel industry. He said that in the long view the demand for steel must continue to grow and that steel must remain the most important material in the world. This, Sir Walter suggested, was because iron ore was one of the commonest and the most easily smelted of all the metallurgical ores.

Sir Walter went on to refer to the fact that in the period between the two world wars world production of steel rose from 76,000,000 tons to 133,500,000 tons a year and that by the end of 1953 it had reached 230,500,000 tons, or three times what it was in 1918. During that period of thirty-six years, Sir Walter said, steel production in the United Kingdom did not rise above the 1918 figure of 9,500,000 tons until 1935; between then and 1953 it increased by 7,750,000 tons. It could be shown, therefore, Sir Walter continued, that the growth of the world's steel production had been rapid. It was quite natural to ask how long the present rate of growth would continue or how long the present level of demand could be maintained. No one, of course, could give the answer, though, statistically, it was said that the consumption of steel and the standard of living were very closely linked. If, Sir Walter commented, that statistical deduction was accepted, it followed that if the world succeeded in raising progressively its standard of living, the demand for steel would go on increasing.

Sir Walter then spoke about the export market and about the competition likely to be encountered. He said that in many parts of the world where the standard of living had been low, the standard of living and the demand for steel might grow faster than in the United Kingdom. If so, Sir Walter added, the world demand, which for this country meant export demand, would grow faster because in backward countries, even if they began to make steel for themselves, it would be some years before they could make enough to keep up with their expanding demand. In looking at the export market, however, there were two other factors to take into account. First, a large part of the steel sold in the home market was sold in the form of finished goods, such as motor-cars, railway material and many kinds of machinery. Other steel-making countries which sold steel and finished steel goods in export markets were increasing their production. Secondly, to that increase had to be added the production of countries which were beginning to make their own steel. Both those factors, Sir Walter emphasised, were a warning that competition in export markets would increase. This country must, therefore, be re-equipping itself to meet competition.

Investment in Human Energy

In a "budget memorandum" which it has sent to the Chancellor of the Exchequer, the National Union of Manufacturers says that what is needed now is a measure of investment in human energies, in order to liberate the will to work, to invest and take risks, and to shoulder forward-looking decisions. Reduced taxation, it is suggested, should be regarded as the key to greater production, and not its result.

The memorandum says that, to live by its trade in a new world of scientific discovery and intensified competition, this country must use to the full all its qualities of skill, daring and initiative. The level of taxation to-day, it asserts, is a major obstacle to their deployment. Many leaders of British industry, the memorandum continues, have publicly reiterated the considered view that the weight of taxation is hampering industrial development. Their observations reflect responsible and informed opinion, presenting a formidable body of evidence, that the State takes too high a proportion of the national income in taxation, higher certainly, the memorandum claims, than in any country competing with the United Kingdom in the markets of the world. The National Union of Manufacturers suggests that "this heavy burden tends to deprive British industry both of financial resources and of the will to risk what resources are left to it." Neither the successful exercise of judgment and ability nor the successful essay of risk, the memorandum observes, is adequately rewarded. With certain favourable trends in the economy and the promise of a substantial surplus at the end of the financial year, now is the time, the National Union of Manufacturers declares, for a bold and imaginative step forward from the "incentive budget" of 1953. A substantial relief in the rate and application of income tax, the memorandum adds, would provide the most general incentive, and a substantial reduction in the purchase tax would remove a serious distortion in the cost of living. Other points made in the memorandum are that the profits tax on undistributed profits should be abolished, and that there should be a reduction in the existing duty of 2s. 6d. a gallon on hydrocarbon oils.

There is also a suggestion about fuel saving equipment. The memorandum says that the investment allowance of 20 per cent granted last year will cover expenditure in the long term on the installation of fuel saving plant. The National Union of Manufacturers nevertheless considers that such expenditure is in a special category, serving as it does both fuel economy and smoke abatement, and should receive short-term encouragement by being allowed as a revenue expense in the year in which it is incurred.

Coal Production and Consumption

Coal output in Great Britain last week amounted to 4,544,800 tons, which was about 20,000 tons less than the total for the corresponding week of last year. In the first six weeks of this year, the saleable output of coal totalled 26,721,900 tons, which was about 800,000 tons below the total for the comparable period of 1954. The decline was about equally shared between deep-mined and opencast output. Colliery manpower has been increasing a little in recent weeks, the number of wage-earners on the books on February 5th being 708,500, of whom 290,600 were face workers.

Coal consumption in the first five weeks of this year amounted to 25,040,000 tons, which was 194,000 tons below the amount consumed in the corresponding weeks of last year. Inland consumption was higher, but the figures for exports and bunkers were lower. Coal imports in the first five weeks of the year were about 800,000 tons, compared with 79,000 tons in the corresponding weeks last year. Distributed stocks on February 5th were 12,722,000 tons, or about 2,000,000 tons less than on the corresponding date of last year.

Personal and Business

Appointments

SIR JAMES REID YOUNG has joined the board of Borg-Warner, Ltd., Letchworth, Herts.

MR. J. S. GERRARD has been appointed senior engineer on the staff of Metal and Pipeline Endurance, Ltd.

MR. O. D. GWILLIAM has been appointed works manager of W. C. Holmes and Co., Ltd., Huddersfield.

GEORGE KENT, Ltd., announces the appointment of Mr. C. W. Chandler as manager of the Hibbert Street works, Luton.

MR. H. WEST has been appointed chief engineer and a member of the "Terylene" council of Imperial Chemical Industries, Ltd.

J. E. BATY AND CO., Ltd., announces the appointment of Mr. J. Hews, 57, Arnold Avenue, Coventry, as Midlands representative.

MR. R. M. FAIRFIELD, M.I.Mech.E., M.I.E.E., has joined the board of British Insulated Callender's Cables, Ltd., as director of production and engineering.

MR. M. N. HENNESSY has been appointed press and public relations officer to the National Union of Manufacturers in succession to the late Mr. C. J. Rhodes.

MR. LESTER J. BRAIN has been appointed managing director of de Havilland Aircraft Proprietary, Ltd. of Australia. He has been chief executive of Trans-Australia Airlines since 1946.

DUNLOP, Ltd., announces the appointment of Mr. George Vaughan as works manager of the Brynmawr factory. Mr. J. W. Tidswell has been appointed works manager of the factory at Hirwaun.

DR. PERCY DUNSHEATH, of W. T. Henley's Telegraph Works Company, Ltd., has been appointed an honorary member of the Conference Internationale des Grands Reseaux Electriques (C.I.G.R.E.).

THE PENINSULAR AND ORIENTAL STEAM NAVIGATION COMPANY announces that Captain G. C. Forrest, R.D., R.N.R., the master of the liner "Arcadia," has been appointed as commodore of the company's fleet.

BLACKBURN AND GENERAL AIRCRAFT, Ltd., states that Mr. Thomas Bancroft has been appointed a director of Blackburn (Dumbarton), Ltd., in succession to Mr. W. A. Hargreaves, who has retired for health reasons.

MR. G. N. VANSITTART has been elected chairman of Vauxhall Motors, Ltd., Luton, in succession to Sir Charles Bartlett, who retired at the end of last year. Mr. F. V. Barker, factory manager, has been appointed a director.

COLONEL G. W. RABY, M.I.Mech.E., has been appointed deputy director (engineering) of the United Kingdom Atomic Energy Authority's research group at Harwell. Mr. D. E. H. Peirson has been appointed secretary to the United Kingdom Atomic Energy Authority.

MR. V. C. MILES has been appointed assistant sales manager of the British Thermostat Company, Ltd., Sunbury. For the last six years he has been Midlands area manager for the Teddington Group (the parent company) in which position he is now succeeded by Mr. L. E. Nicholls.

METROPOLITAN-VICKERS ELECTRICAL COMPANY, Ltd., states that Mr. R. P. Horlock, M.I.E.E., manager of the Sheffield office, has transferred to Metropolitan-Vickers Electrical Export Company, Ltd., as manager for Canada. He is succeeded as manager at Sheffield by Mr. R. S. D. Bagnall, M.I.E.E.

E. H. BENTALL AND CO., Ltd., Maldon, Essex, states that Mr. H. A. Hague has become home sales manager. Hitherto he has been responsible for both home and export sales. Mr. D. D. West has been appointed export sales manager and is now engaged on a tour of the West Indies and Central American countries.

POWER JETS (RESEARCH AND DEVELOPMENT), Ltd., states that Captain (E) E. A. G. Whittle, R.N., and Mr. J. H. Pitchford, M.I.Mech.E., have been appointed directors. Captain (E) E. J. H. Kirby, R.N., has resigned from the board owing to change of Admiralty duties and Rear Admiral W. G. Cowland has resigned owing to pressure of other work.

MONSANTO CHEMICALS, Ltd., states that Dr. W. A. Hayward, works manager at the Ruabon factory, has been appointed assistant to the managing director, Mr. Philip A. Singleton. After visiting Australia and New Zealand, Dr. Hayward will establish headquarters in St. Louis, U.S.A. Mr. E. V. Weekes, formerly area manager at the Ruabon factory, has been appointed works manager in succession to Dr. Hayward.

MR. W. D. AKESTER has been appointed sales director of Ransomes, Sims and Jefferies, Ltd., Ipswich, with responsibility for co-ordinating home and export sales. Mr. J. S. Canning has been appointed home sales manager. Mr. Canning, who was managing director of Ransomes, Sims and Jefferies (Watford), Ltd., retains his seat on the board of that company, being assisted by Mr. E. J. Garrod as works manager and Mr. R. Grindley as commercial manager.

Business Announcements

CRAVEN BROTHERS (MANCHESTER), Ltd., Reddish, Stockport, announces the retirement of Mr. W. Owen, M.I.Mech.E., chief designer and research engineer of the gear hobbing machine section.

RANSOME AND MARLES BEARING COMPANY, Ltd., Newark-on-Trent, has opened a branch office for Scotland at 310, Perth Road, Dundee (telephone, Dundee 66155). The Leeds branch office has been moved to St. Paul's House, 20–22, St. Paul's Street, Leeds, 1 (telephone, Leeds 32094).

HUMPHREYS AND GLASGOW, Ltd., Humglas House, Carlisle Place, London, S.W.1, is establishing a branch office at 82, Elizabeth Street, Sydney, N.S.W. Mr. A. S. Humphrys and Mr. J. R. Spangaro, at present senior engineers of the firm's London staff, are to take charge of the new branch which, it is hoped, will be in operation early in May next.

ASSOCIATED COMMERCIAL VEHICLES, Ltd., The Austin Motor Company, Ltd., and Rootes Motors, Ltd., state that, as part of the plans to take over and maintain the Suez Canal base after the withdrawal of the British Forces, a new contracting company entitled Suez Contractors (Vehicles), Ltd., has been formed. The object of this company is to maintain the vehicles, engineering plant and general stores at the base ordnance depot, engineers' stores depot and base workshops in accordance with the Anglo-Egyptian Treaty signed last October, whereby the Suez Canal base will in future be maintained by civilians. A number of British firms have agreed to participate in the maintenance of the base in the national interest. The directors of the new company are :—Mr. W. R. Black, Lord Brabazon of Tara, P.C., Sir Leonard Lord, Major-General E. H. Clayton, Sir William Rootes, and Sir Reginald Rootes. Mr. G. Grant Richards, A.M.I.Mech.E., has been appointed general manager of the company and Vice-Admiral (S) Sir William McBride has been appointed London manager and secretary. The offices of the company will shortly be established at 96, Piccadilly, London, W.1.

Contracts

THE POWER-GAS CORPORATION, Ltd., Stockton-on-Tees, has been awarded a contract for the reconstruction of an existing sulphuric acid plant at the Flixborough Works of Nitrogen Fertilisers, Ltd. The new equipment will be built to the designs of Chemiebau Dr. A. Zieren G.m.b.H., and will comprise a converter with a capacity of 140 tons per day of monohydrate, an acid separator, waste heat boiler, and ancillary equipment.

DAVY AND UNITED ENGINEERING COMPANY, Ltd., Sheffield, has received an order from S.A. des Acieries et Forges de Firminy for a 6000-ton hydraulic wheel forging press. The press will be installed in the French firm's works at Malo-les-Bains and will be supplied along with two 600 h.p. hydraulic pumps, 400-gallon air-hydraulic accumulator, hydraulic intensifier and other ancillary equipment. It is expected that the greater part of manufacture will be carried out in the works of Davy-United's Glasgow subsidiary, Duncan Stewart and Co., Ltd.

SIMON HANDLING ENGINEERS, Ltd., of Stockport, has completed agreements in fulfilment of a contract made a year ago with the Turkish Government for the building of four large grain elevators, three complete flour mills, fifteen plants for the manufacture of animal feeding stuffs, and five mobile pneumatic grain handling plants and sets of seed grain cleaning plants. Simon Handling Engineers, Ltd., will build and equip grain elevators at Mersin, Ankara and Konya, and will equip a grain elevator at Tekirdag. The elevators will together provide 240,000 tons of grain storage accommodation. Henry Simon, Ltd., will equip one flour mill at Konya and two others, and will supply the machinery for the animal feeding stuffs plants. The contract amounts in total to the equivalent of £8,500,000 sterling, of which nearly £5,500,000 sterling represents machinery, equipment and technical services to be supplied from the United Kingdom. The remainder, approximately £3,000,000, will be paid directly in Turkish currency.

Miscellanea

CORRECTION.—In our issue of February 4th, page 168, under the heading "Books Received," we published a notice concerning the *Radio and Television Engineers' Reference Book*, published by George Newnes, Ltd. We stated erroneously that this was the thirteenth edition, whereas, in fact, it is the first edition.

PROFESSOR NERVI'S LECTURE.—We recently announced that Professor Nervi, the Italian architect and structural engineer, would be delivering a lecture this month at the Central Hall, Westminster. We now learn from the Cement and Concrete Association that the lecture will not be delivered, as Professor Nervi has had to go to hospital.

SOCIETY OF ENGINEERS' PREMIUM.—On Monday, February 7th, at the headquarters of the Society of Engineers, Miss M. L. Burgess was presented with a premium by the Society. This is only the third time in its 100 years' history that the Society of Engineers has awarded a premium to a woman, the last occasion being in 1930 to Miss Amy Johnson.

LECTURES ON CORROSION PROTECTION OF BURIED STRUCTURES.—A course of five lectures entitled "Corrosion and Protective Measures for Buried and Submerged Structures" is to be given at Northampton Polytechnic, St. John Street, London, E.C.1, by K. A. Spencer ; the lectures will be on Monday evenings at 7 p.m., starting on March 7th. They will deal with the mechanism of corrosion of buried and submerged structures, coatings for buried and submerged structures, cathodic protection methods, and the correlation of cathodic protection with structural engineering design.

INDUSTRIAL SERVO POWER UNIT.—An industrial servo power unit designed to provide all the power supplies needed for operating a servo motor has been marketed by the Edison Swan Electric Company, Ltd., 155, Charing Cross Road, London, W.C.2. In conjunction with a servo motor such as the Evershed and Vignoles "FA2" equipment, the new power unit can be used for various purposes, such as high power voltage stabilisation, controlled speed drives, follower systems or process control. An input signal of 0·2V causes the maximum d.c. excitation to be applied to the motor field (80mA centre tapped) ; the armature current is 1mA, d.c. The servo unit will operate from a 200-250V, 50 c/s single phase supply.

DRAWING STORAGE CABINET.—A new system for the storage of drawings has been introduced under the trade name "Planstore" by James H. Randall and Son, Ltd., Paddington Green Works, London, W.2. The steel storage cabinet used is made in three sizes, 3ft, 4ft, or 7ft high and 3ft wide, with a depth sufficient to take double elephant or antiquarian drawings. The front of this cabinet is divided into a number of rectangular compartments, each of which is deep enough to support a rectangular plastic socket. Each socket has in its rear end a cylindrical bore, into which the end of a rolled drawing can be fitted to a depth which is sufficient for the drawing to be self-supporting when the socket is inserted in its compartment. The front of each socket has two inclined faces, on which identification labels for the drawings it carries can be fitted. Up to five drawings of various sizes can be placed in each socket.

HYDRO-ELECTRIC DEVELOPMENT IN NORTHERN IRELAND.—Two schemes for hydro-electric development are being examined by the Northern Ireland Government, which has approved the construction of a large generating station on a site to be selected outside Belfast. This information was given in the Queen's Speech, which was read by the Governor (Lord Wakehurst) at the opening of a new session of the Northern Ireland Parliament on February 8th. The Speech added : "The highest importance is attached to the benefits that may result from the application of atomic energy to industrial uses and, in particular, to the generation of electricity. Arrangements have been made to ensure that full advantage can be taken of the developments now proceeding in Great Britain as soon as these reach a point where they may profitably be applied in Northern Ireland."

CABLE MAKER'S EXHIBITION.—An exhibition is being held at the Russell Hotel, London, W.C.1, by W.T. Henley's Telegraph Works Company, Ltd., until February 25th (excluding Saturday and Sunday) from 2.30 to 7 p.m. The exhibition falls into two main parts : the first covers cables, distribution equipment and other products made in the company's factories at Gravesend, Woolwich, Birtley and Cradley Heath ; the second consists of a number of demonstrations designed to show some of the apparatus used in normal routine testing in the various works. These demonstrations include : cable diameter control, using a device for the automatic control of the diameter of extruded cables ; the small Henley spark tester, used for continuous voltage testing of rubber or plastic covered cores ; the Henley continuity tester, for checking the continuity of a cable conductor after each process operation ; and a "Shadowgraph" projection microscope for the examination of the profiles of cable sections, &c. Another demonstration shows the use of an electronic test panel designed specially for testing the Henley earth-leakage circuit breaker. In this test panel the circuit breaker is inserted manually, whereupon the series of tests specified in B.S. 842 : 1939 is carried out in the required sequence until completed satisfactorily or until an unsatisfactory result is recorded, indicating rejection. A series of lectures is being given in conjunction with the exhibition, including "Rubber and Synthetic Rubber Thermoplastics," by H. T. Tew, on Monday, February 21st, and "The Manufacture of Electric Power Cables," by W. H. Lythgoe, on Wednesday, February 23rd.

British Patent Specifications

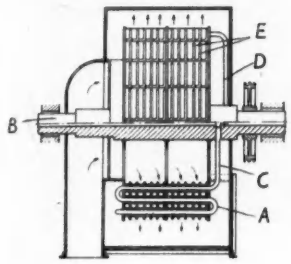
When an invention is communicated from abroad the name and address of the communicator are printed in italics. When an abridgment is not illustrated the specification is without drawings. The date first given is the date of application; the second date, at the end of the abridgment, is the date of publication of the complete specification.

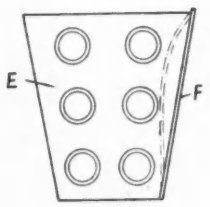
Copies of specifications may be obtained at the Patent Office Sales Branch, 15, Southampton Buildings, Chancery Lane, W.C.2, 2s. 8d. each.

HEAT EXCHANGERS

722,058. June 20, 1952.—ROTARY TUBULAR HEAT EXCHANGERS, Helene Simmon, Dornbacherstrasse 27, Vienna XVII; Elfriede Bauman, Dornbacherstrasse 84, Vienna XVII; and Hildegard Graf, Dornbacherstrasse 27, Vienna XVII, trading as Maschinenfabrik Ing. Hans Simmon.

The invention relates to a heat exchanging device for transferring heat from a flowing gas or vapour to a fluid flowing through a tube system of a rotor in which tube groups lying in radial planes are connected by common rib plates. As will be seen from the drawing, the rotor consists of tubes *A*, constituting a nest of coils. The liquid to be heated





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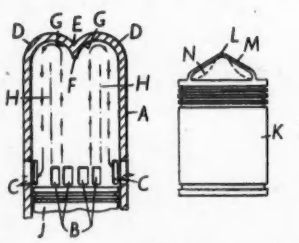
enters the coils from one end of the hollow axle *B* through the radial tube *C*, and then flows back through a second radial tube *D*, opening into the other end of the hollow axle, whence it flows out. Rotation of the rotor causes a fan effect drawing hot gases through the inlet of the casing end through the rotor and driving them out of the casing outlet, the direction of the passage of the heating gases being indicated by arrows. According to the invention, the ribs *E* on the tubes *A* are turned up into the shape of blades *F* on one of the radial edges, so as to increase the fan effect of the rotor. As is shown, the blades may extend radially and be formed as flat surfaces or they may be concave or convex. Also the blade-carrying ribs may alternate with bladeless ribs.—*January* 19, 1955.

INTERNAL COMBUSTION ENGINES

722,285. April 30, 1952.—TWO-STROKE ENGINES, The Austin Motor Company, Ltd., Longbridge Works, Northfield, Birmingham; and John Harold Weaving, Ph.D., of the company's address.

The invention relates to two-stroke internal combustion engines of the loop scavenge type. Referring



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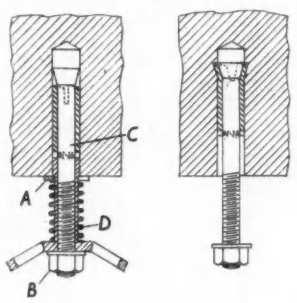
to the drawing, the cylinder *A* is provided with two diametrically opposed sets of inlet ports *B* and two opposed sets of exhaust ports *C* at right angles to the inlet ports. The cylinder head is generally of dome shape, shown at *D*, but is contoured to form a diametrical cusp *E* of symmetrical form and constant cross-section, with an apex *F*. The side faces *G* of the cusp diverge from the axial diametrical or centre plane of the two sets of inlet ports *B* and merge out into the dome *D* of the cylinder head. With this arrangement the inflows from the two opposed sets of inlet ports *B* impinge and merge to form an incoming column of gases in the central transverse zone of the cylinder defined theoretically between chordwise planes, indicated by the chain lines at *H*, parallel with the centre plane of the inlet ports and separated approximately by the overall width of the sets of inlet ports. The deflector cusp *E* divides the incoming column of gases in the centre plane of the inlet ports *B* so as to form two streams, the side faces *G* directing the two separate streams towards opposite sides of the cylinder. The dome *D* of the cylinder then completes reversal of the direction of flow of the two streams, which return through the two side zones of the cylinder towards the two sets of exhaust ports. The operation is satisfactory with a conventional piston, as shown at *J*, but if desired the scavenge may be assisted by the provision of a special piston *K*, the crown of which is formed as an appropriately shaped deflector *L*. This deflector is of cruxiform shape in plan view, comprising essentially four right-angularly disposed radial fins *M*, any adjacent pair of which, in conjunction with the piston crown, which is curved up between the fins, as will be seen at *N*, afford a concave gas-directing surface immediately confronting a set of inlet ports *B* or exhaust ports *C* when the piston is at the bottom of its stroke during the period of scavenge.—*January* 19, 1955.

BEARINGS AND SUPPORTS

722,340. March 14, 1952.—WALL BOLT AND FOUNDATION BOLT, Thomas Arthur Rees, 64, Cantley Lane, Doncaster, Yorkshire.

In the drawing, the left-hand view shows the bolt device and wrench assembled and inserted in the



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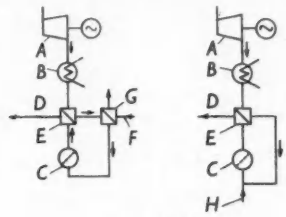
bolt hole, the slotted washer *A* marking the correct depth of insertion. When placed in position in the bolt hole the sleeve is rotated by the wrench by means of serrated edges on the casing and the wrench carrying the bolt *C* and nut *B* around with it. As nut *B* is gradually tightened up it draws the bolt head into the sleeve thus causing the sleeve end to expand. The increasing diameter of the sleeve end creates pressure against the inclined walls of the conical cavity being gradually formed, which pressure tends to force the sleeve inwards, thus providing the necessary forward movement for continuous boring by the end of the sleeve which is proud with cutting tips. The spring *D* compresses as required to conform with this inward movement, and as the inward movement of the sleeve exceeds the outward movement of the bolt the final position of the bolt head is slightly nearer the inner extremity of the hole than when first inserted. The right-hand view shows the bolt and the sleeve end expanded and ready for use.—*January* 26, 1955.

STEAM POWER PLANTS

722,688. May 15, 1953.—CONDENSATE TREATMENT FOR STEAM PLANTS, Sulzer Frères Société Anonyme, Winterthur, Switzerland.

The invention relates to condensate treatment for steam plants in which condensate is recirculated, recovered and used again for feeding the boiler. In the plants shown in both views of the drawing exhaust steam from a power turbine *A* is condensed in a condenser *B*. After further cooling the condensate is passed through a water softening device *C* and is then discharged through a pipe *D* as feed water for the boiler. In the plant shown in the left-hand view the hot condensate from the condenser *B* flows through a heat exchanger *E* in which it gives up a substantial proportion of its heat content to the colder purified condensate discharged from the water softener *C*. In this way the heat extracted from the condensate in the heat exchanger is recovered in the feed water. The partially cooled condensate flows from the heat exchanger *E* into a further heat exchanger *G*, in which it is further cooled by cooling water supplied through a pipe *F* down to a temperature compatible with the effective operation of the water softening device. In the heat exchanger *G* only a fraction of the heat which has to be withdrawn from the condensate before it enters the water softening device is taken away from the plant by the cooling water, so that the losses are relatively small. If a supply of sufficiently cool fresh water is available, the further cooling in the heat exchanger *G* can be dispensed with, as in the arrangement shown in the right-hand view. In this case the hot condensate coming from the condenser *B* gives up most of its



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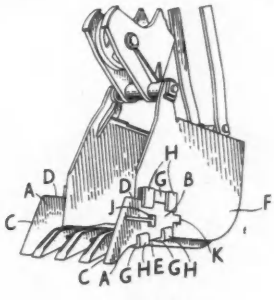
heat to the cold purified condensate discharged from the water softening device *C*. Cool fresh water is introduced into the partially cooled condensate through a pipe *H*, thus reducing the temperature of the water mixture to a value compatible with the effective operation of the water softening device. The purified condensate then takes up again in the heat exchanger *E* the heat which was previously withdrawn from it on the other side of the heat exchanger, and it then passes through the pipe *D* as feed water for the boiler. With this arrangement there are practically no heat losses, apart from the unavoidable losses arising from imperfect insulation.—*January* 26, 1955.

EXCAVATORS

722,618. April 18, 1952.—EXCAVATOR BUCKETS, Thomas Smith and Sons (Rodley), Ltd., Crane and Excavator Works, Rodley, Leeds; and James Thomas Upex, of the company's address.

The invention relates to drag, shovel or backhoe excavator buckets. It is usual with such buckets to provide side cutters mounted on the leading edge of the side of the bucket, such cutters being bolted in position. The chief object of the invention is to provide a new and improved construction of side cutters which does away with bolts, the side cutters



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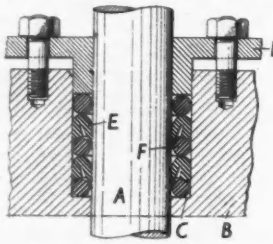
being connected to the bucket by a wedging action. Referring to the drawing, each side cutter *A* is formed by a plate *B* having a cutting edge *C*, an upper edge *D*, which may be parallel to the axis of the bucket and a lower edge *E* inclined upwards. The outer sides of the bucket *F* are each provided with guides *G* for engaging the upper and lower edges *D* and *E* of the side cutter. The guides also incorporate lugs or extensions *H*, which engage the outer face of the side cutter. Each side cutter has a suitable projection *J* on its outer side face to facilitate removal by striking with a hammer in a forwards direction. The side cutter also has a locking device at the rear end, which may consist of a small projection *K* which can be bent into a recess provided for that purpose in the bucket side plate.—*January* 26, 1955.

BEARINGS AND SUPPORTS

722,462. August 8, 1952.—PACKINGS BETWEEN RECIPROCATING OR ROTATING MEMBERS, Ronald Trist and Co., Ltd., Bath Road, Slough, Buckinghamshire. (*Inventor: William Wilson.*)

The drawing shows a stuffing box in which a reciprocating rod *A* passes through a housing *B* and rings held in a cavity *C* by a gland *D*, which is secured by bolts to the housing. The rings are of two kinds, there being two rings *E*, each having a body which is roughly U-shaped in section, with the limbs extending axially. The inner limb of each ring is tapered towards its edge to form a single lip, which engages

the moving rod. The outer limb has a wide end. The other rings are of circular section and are made of more resilient material. There is one resilient ring *F* interposed between two lipped rings and one at



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each outer end. The resilient nature of the spacing rings prevents damage by overloading of the stuffing box axially, and it allows some floating movement of the whole packing.—*January* 26, 1955.

Launches and Trial Trips

CAPETAN CARRAS, cargo liner ; built at the Neptune Works of Swan, Hunter and Wigham Richardson, Ltd., for the Tramp Chartering Corporation of Panama ; length between perpendiculars 450ft, breadth moulded 62ft, depth moulded to shelter deck 40ft 4in, deadweight 13,320 tons on 30ft 7¼in draught ; five holds arranged to carry grain in bulk ; ten 10-ton, one 20-ton and one 30-ton derricks, three 180kW diesel-driven generators, one 50kW diesel-driven generator ; Swan Hunter-Doxford oil engine, five cylinders 670mm diameter by 2320mm combined stroke, 5500 b.h.p. at 115 r.p.m. Trial, January 26th.

FILBY QUEEN, trawler ; built by John Lewis and Sons, Ltd., for Talisman Trawlers, Ltd.; length overall 113ft 6in, length between perpendiculars 100ft, breadth moulded 20ft, depth moulded 10ft 9in ; one 15kW diesel-driven generator, one 10kW belt-driven generator ; Crossley H.R.N.6 diesel engine, 440 b.h.p. at 300 r.p.m., with shaft extension for trawl winch drive. Trial, January 27th.

WOOLWICH, cargo tramp ; built by the Caledon Shipbuilding and Engineering Company, Ltd., for the Britain Steamship Company, Ltd. ; length between perpendiculars 435ft, breadth moulded 58ft 6in, depth moulded to shelter deck 38ft, deadweight 10,000 tons on 27ft draught, service speed 13 knots ; six cargo holds, two 3-ton and ten 10-ton derricks, steam deck machinery, deck water ballast tanks ; three 100kW diesel-driven generating sets ; Stephen-Doxford two cycle oil engine, 4400 b.h.p., two oil-fired boilers.—Launch, February 8th.

SOUTHERN SATELLITE, oil tanker ; built by the Furness Shipbuilding Company, Ltd., for Chr. Salvesen and Co. ; length between perpendiculars 525ft, breadth moulded 71ft, depth moulded 39ft 3in, deadweight 17,500 tons on 30ft 6½in summer draught, designed trial speed 15 knots ; twenty-seven cargo oil tanks, two pump rooms, four 500 tons per hour cargo oil pumps, four 75 tons per hour stripping pumps, two 95kW diesel-driven generators ; N.E.M.-Doxford single-acting, two stroke oil engine, six cylinders, 670mm diameter by 2320mm combined stroke, 6800 b.h.p. at 119 r.p.m., two Scotch boilers.—Launch, February 8th.

MANXMAN, cross-channel steamer ; built by Cammell Laird and Co. (Shipbuilders and Engineers) Ltd., for the Isle of Man Steam Packet Company, Ltd. ; length overall 344ft 3in, length between perpendiculars 325ft, breadth moulded 47ft, depth moulded to shelter deck 26ft, gross tonnage 2500, service speed 21 knots ; 2300 passengers in two classes ; four passenger decks, auxiliary bow rudder, six 28ft lifeboats, two 200kW diesel-driven generators ; two sets of Pametrada double reduction geared turbines each consisting of an ahead impulse turbine and an astern impulse turbine, designed power is developed at 275 r.p.m. of the propeller, steam is supplied at 350 lb per square inch and 650 deg. Fah. by two Babcock and Wilcox marine water-tube boilers, burning oil fuel on closed stokehold system.—Launch, February 8th.

Catalogues

G. WADDINGTON AND SON, Ltd., Newland, Hull.—Handbook of " Furno " industrial gloves.

DANKS OF NETHERTON, Ltd., Netherton, Dudley, Worcs.—General catalogue covering the company's products.

JENKS BROTHERS, Ltd., Britool Works, Bushbury, Wolverhampton.—Leaflet 460/1, " Jenbro " open jaw wrenches.

LACRINOID PRODUCTS, Ltd., Gidea Park, Essex.—Illustrated booklet on the Lacromatic process for the barrel finishing of metals.

THE HOFFMANN MANUFACTURING COMPANY, Ltd., Chelmsford, Essex.—Card folder, " Getting the Best Out of Hoffmann Ball and Roller Bearings."

THE TRANSFORMER AND ELECTRICAL COMPANY, Ltd., Eastern Works, Eastern Road, London, E.17.—Catalogue III, Power and Distribution Transformers.

PLESSEY COMPANY, Ltd., Ilford, Essex.—Booklet describing Plessey solderless wiring connection for light and heavy duty. Two booklets, " Hydraulic Pumps " and " Hydraulics in Industry."

Forthcoming Engagements

Secretaries of Institutions, Societies, &c., desirous of having notices of meetings inserted in this column, are requested to note that, in order to make sure of their insertion, the necessary information should reach this office not later than a fortnight before the meeting. In all cases the TIME *and* PLACE *at which the meeting is to be held should be clearly stated.*

BRITISH INSTITUTION OF RADIO ENGINEERS

Wed., Feb. 23rd.—LONDON SECTION : School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1, " A Versatile Electronic Engine Indicator," R. K. Vinycomb, 6.30 p.m.——S. WALES SECTION : Glamorgan Technical College, Treforest, " The Training of Radio Engineers," H. W. French, 6.30 p.m.

CHEMICAL SOCIETY

Fri., Feb. 25th.—ABERDEEN BRANCH : Robert Gordon's Technical College, Aberdeen, " Corrosion Processes: Their Causes and Prevention," F. Wormwell, 7.30 p.m.

HULL CHEMICAL AND ENGINEERING SOCIETY

Tues., Feb. 22nd.—Church Institute, Hull, " The Technology of Milk Condensing," G. B. Wright, 7.30 p.m.

ILLUMINATING ENGINEERING SOCIETY

Fri., Feb. 25th.—BIRMINGHAM CENTRE : Regent House, St. Phillips' Place, Colmore Row, Birmingham, Annual General Meeting, " Terms and Techniques for Satisfactory Lighting," J. G. Holmes, 6 p.m.

Mon., Feb. 28th.—LEEDS CENTRE : E.L.M.A. Lighting Service Bureau, 24, Aire Street, Leeds, 1. " Prescribing for Seeing," M. L. Berson, 6.15 p.m.——LEICESTER CENTRE : E. Midlands Electricity Board, Charles Street, Leicester, " Lighting Maintenance Problems," J. W. Strange, 6 p.m.

INCORPORATED PLANT ENGINEERS

Thurs., Feb. 24th.—SHEFFIELD AND DISTRICT BRANCH : Grand Hotel, Sheffield, " Air Pollution Problems," 7.30 p.m.

Fri., Feb. 25th.—BIRMINGHAM BRANCH : Imperial Hotel, Temple Street, Birmingham, " The Scientist and Non-Scientist in Industry," J. H. Fremlin, 7.30 p.m.

Mon., Feb. 28th.—W. AND E. YORKSHIRE BRANCH : The University, Leeds, " Steam Trapping is Common Sense," F. Blezzard, 7.30 p.m.

INSTITUTE OF BRITISH FOUNDRYMEN

Sat., Feb. 19th.—E. MIDLANDS BRANCH : College of Arts, Derby, " Factors Governing Graphite Formation in Cast Iron," P. A. Russell, 6 p.m.

Wed., Feb. 23rd.—BIRMINGHAM BRANCH : James Watt Memorial Institute, Great Charles Street, Birmingham, " Heat Resisting Cast Irons," M. M. Hallett, 7.15 p.m.——LONDON BRANCH : Waldorf Hotel, London, W.C.1, " Some Aspects of Metallurgical Control in the Modern Steel Foundry," N. Y. Newton, 7.30 p.m.

INSTITUTE OF FUEL

Thurs., Feb. 24th.—SCOTTISH SECTION : North British Hotel, Edinburgh, " Some Aspects of the Problem of Air Heating," J. F. S. Kistruck, 7 p.m.

INSTITUTE OF MARINE ENGINEERS

Mon., Feb. 21st.—JUNIOR LECTURE : College of Technology, Belfast, " Reciprocating Steam Engines," G. Yellowley, 7.30 p.m.——W. OF ENGLAND SECTION : Grand Hotel, Bristol, " Marine Machinery of the Immediate Future from the Shipowners' Point of View, with Special Reference to Costs," J. E. Church, 7 p.m.

Tues., Feb. 22nd.—S. WALES SECTION : S. Wales Institute of Engineers, Cardiff, " Atlantic Shipbuilding Company, Ltd., Welded Ship Programme," M. H. A. Stevens, 7.15 p.m.

Fri., Feb. 25th.—S. WALES SECTION : Technical College, Mount Pleasant, Swansea, " Marine Diesel Engines," A. G. Arnold, 7 p.m.

Mon., Feb. 28th.—N.E. COAST SECTION : Technical College, Northgate, Darlington, " Metallurgy in Marine Engineering," J. E. Garside, 7 p.m.

INSTITUTE OF METALS

Mon., Feb. 21st.—SHEFFIELD LOCAL SECTION : University Buildings, St. George's Square, Sheffield, " Recent Developments in Colour Television," L. C. Jesty, 7.30 p.m.

Thurs., Feb. 24th.—BIRMINGHAM LOCAL SECTION : James Watt Memorial Institute, Great Charles Street, Birmingham, " Current Work of the British Non-Ferrous Metals Research Association," G. L. Bailey, 6.30 p.m.

INSTITUTE OF PETROLEUM

Mon., Feb. 21st.—26, Portland Place, London, W.1, " The Modern Planning of Regional Surveys for Petroleum," P. Leicester, 5.30 p.m.

INSTITUTE OF REFRIGERATION

Thurs., Feb. 24th.—Institution of Mechanical Engineers, 1, Birdcage Walk, Westminster, London, S.W.1, " Sub-Soil Temperatures and Frost-Heave," G. Yates Pitts, 5.30 p.m.

INSTITUTE OF ROAD TRANSPORT ENGINEERS

Tues., Feb. 22nd.—N.E. ENG. GROUP : Royal County Hotel, Durham, " The Costing of Vehicle Maintenance," H. Rossington, 7 p.m.

INSTITUTE OF THE MOTOR INDUSTRY

Tues., Feb. 22nd.—METROPOLITAN REGION : 40, Queen's Gate, London, S.W.7, " Industrial Dermatitis with Particular Reference to the Motor Industry," G. N. Chadman, 7.30 p.m.

INSTITUTE OF WELDING

Fri., Feb. 25th.—BIRMINGHAM BRANCH : Midland Institute, Paradise Street, Birmingham, 1, " The Inspection and Testing of Welds," A. H. Goodger, 6 p.m.——S. LONDON BRANCH : Technical College, Kingston, " Fusion Welding," V. W. Clack, 7 p.m.

INSTITUTION OF CHEMICAL ENGINEERS

To-day, Feb. 18th.—N.W. BRANCH : College of Technology, Manchester, " A New Technique for Particle Size Distribution Analysis by Centrifugal Sedimentation," J. K. Donoghue and W. Bostock, 7 p.m.

INSTITUTION OF CIVIL ENGINEERS

Tues., Feb. 22nd.—RAILWAY MEETING : Great George Street, Westminster, London, S.W.1, " Folkestone Warren Landslips, 1948–1950 Investigation," A. M. Muir Wood ; " Folkestone Warren Landslips : Remedial Measures, 1948–1954," N. E. V. Viner-Brady, 5.30 p.m.

Wed., Feb. 23rd.—N.W. ASSOCIATION : 9, The Temple, 24, Dale Street, Liverpool, " The Significance of the Particle in Civil and Structural Engineering," S. Champion, 6 p.m.

Fri., Feb. 25th.—YORKSHIRE ASSOCIATION : Hotel Metropole, Leeds, " Folkestone Warren Landslips," and " Folkestone Warren Defences," A. M. Muir Wood, 7 p.m.

INSTITUTION OF ELECTRICAL ENGINEERS

Mon., Feb. 21st.—N. MIDLAND CENTRE : Town Hall, Leeds, " Courier to Carrier in Communications," T. B. D. Terroni, 7 p.m.——RADIO SECTION : Savoy Place, London, W.C.2, " The Recent Search for and Salvage of the ' Comet ' Aircraft near Elba," C. G. Forsberg, 5.30 p.m.

Tues., Feb. 22nd.—N. MIDLAND CENTRE : British Electricity Authority, 1, Whitehall Road, Leeds, 1, " Power Factor and Methods of Correction," W. A. Breckneil, 6.30 p.m.—— S.E. SCOTLAND SUB-CENTRE : Douglas Hotel, Galashiels, " Electricity in the Wool Textile Industry," A. J. Francis, 7.30 p.m.

Wed., Feb. 23rd.—SUPPLY SECTION : Savoy Place, London, W.C.2, " High-Voltage Transmission Developments in Sweden," A. Rusck, 5.30 p.m.

Thurs., Feb. 24th.—Grosvenor House, Park Lane, London, W.1, Annual Dinner 7 p.m.

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND

Tues., Feb. 22nd.—39, Elmbank Crescent, Glasgow, " Problems of Stability in Engineering," W. J. Duncan, 7.30 p.m.

INSTITUTION OF LOCOMOTIVE ENGINEERS

Wed., Feb. 23rd.—Institution of Mechanical Engineers, 1, Birdcage Walk, London, S.W.1, " Welding of Steel or Cast Iron Components in Locomotive Manufacture and Maintenance," G. Foster, 5.30 p.m.

INSTITUTION OF MECHANICAL ENGINEERS

To-day, Feb. 18th.—GENERAL MEETING : 1, Birdcage Walk, Westminster, London, S.W.1, " Pulsating Flow Measurement by Viscous Meters with Particular Reference to the Air Supply of Internal Combustion Engines," K. L. Kastner and T. J. Williams, 5.30 p.m.——SCOTTISH GRADUATES' SECTION : Royal Technical College, Glasgow, " Experimental Research at Glengarnock on Ship's Structural Members," K. V. Taylor, 7.30 p.m.

Mon., Feb. 21st.—SCOTTISH A.D. CENTRE : Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, " Some Problems in Lubrication and the Substances called Additives," A. Towle, 7.30 p.m.

Tues., Feb. 22nd.—AUTOMOBILE DIVISION : 1, Birdcage Walk, Westminster, London, S.W.1, Discussion : What should be done about the British Roads," 6.45 p.m.——E. MIDLANDS BRANCH : College of Technology, Loughborough, " Nuclear Reactors and Power Production," Sir Christopher Hinton, 6.30 p.m.——BIRMINGHAM A.D. CENTRE : James Watt Memorial Institute, Great Charles Street, Birmingham, " Engine Research and Development as a Service to Industry : A Personal Experience," J. H. Pitchford, 6.45 p.m.

Wed., Feb. 23rd.—YORKSHIRE BRANCH : Visit to B.I.S.R.A., 2.30 p.m. : B.I.S.R.A., Hoyle Street, Sheffield, " Shock-loading Effects in Electric Overhead Cranes," J. Baker and E. Lightfoot, 6.30 p.m.——N.E. GRADUATES SECTION : King's College, Newcastle upon Tyne, " Aluminium Production in the Scottish Highlands," J. Armour, 7 p.m.

Thurs., Feb. 24th.—EASTERN BRANCH : Red Lion Hotel, Colchester, " Modern Methods of Materials Handling," K. B. Warwick and F. T. Dean, 7.30 p.m.——WESTERN A.D. CENTRE : Royal Hotel, Bristol, " The ' Jaguar ' Engine," W. M. Heynes, 6.45 p.m.

Fri., Feb. 25th.—INDUSTRIAL ADMINISTRATION AND ENGINEERING PRODUCTION GROUP : 1, Birdcage Walk, Westminster, London, S.W.1, Discussion : " Choice of Tolerance in Relation to Production," 6.45 p.m.——SOUTHERN SECTION : Municipal College, Anglesey Road, Portsmouth, " Disc Brakes Applied to Road Vehicles," J. O. Starling, 7 p.m.

INSTITUTION OF POST OFFICE ELECTRICAL ENGINEERS

Wed., Feb. 23rd.—INFORMAL MEETING : Conference Room, Fourth Floor, Waterloo Bridge House, London, S.E.1, " Is Our Telephone Equipment Too Complex ? " F. Scowen, 5 p.m.

INSTITUTION OF PRODUCTION ENGINEERS

To-day, Feb. 18th.—STOKE-ON-TRENT SECTION : Town Hall, Hanley, Stoke-on-Trent, " From Diamond to Spark Machining," G. Fefer, 7.45 p.m.

Mon., Feb. 21st.—MANCHESTER SECTION : Reynolds Hall, College of Technology, Sackville Street, Manchester, 1, " Air Photography in Peace and War," F. C. V. Laws, 7.15 p.m.—— N.E. SECTION : Neville Hall, Newcastle upon Tyne, " Radio-isotopes in Industry," H. Seligman, 7 p.m.

Tues., Feb. 22nd.—LUTON SECTION : N. Herts Technical College, Letchworth, Herts, " Electronics as an Aid to Productivity," J. A. Stokes, 7.15 p.m.

Wed., Feb. 23rd.—LINCOLN SECTION : Technical College, Newark, " Production Control as Applied to Small and Medium Companies," F. T. Hunter, 7.30 p.m.

Thurs., Feb. 24th.—LONDON S.E. REGIONAL MEETING : Royal Empire Society, Northumberland Avenue, London, W.C.2. " Does the National Certificate in Production Engineering Meet the Needs of Industry," J. V. Connolly, 7 p.m.

INSTITUTION OF THE RUBBER INDUSTRY

Fri., Feb. 28th.—Engineers' Club, Albert Square, Manchester, " Limitations of Rubber," G. Gee, 6.45 p.m.

JUNIOR INSTITUTION OF ENGINEERS

To-day, Feb. 18th.—INFORMAL MEETING : Pepys House, 14, Rochester Row, London, S.W.1, " The Atom," S. A. McAuliffe, 7 p.m.

Fri., Feb. 25th.—Pepys House, 14, Rochester Row, London, S.W.1, Adjourned Annual General Meeting, followed by Informal Meeting : " Some Stages in the Refining of Crude Oil," H. W. D. Hughes, 7 p.m.

LIVERPOOL ENGINEERING SOCIETY

Mon., Feb. 21st.—Royal Institution, Colquitt Street, Liverpool, " The Electrification of the Manchester-Sheffield-Wath Lines," J. H. Broughall and K. J. Cooke, 6.30 p.m.

Wed., Feb. 23rd.—24, Dale Street, Liverpool, " The Significance of the Particle in Civil and Structural Engineering," S. Champion, 6 p.m.

MANCHESTER ASSOCIATION OF ENGINEERS

To-day, Feb. 18th.—Engineers' Club, Albert Square, Manchester, " Some Aspects of Drop Forging Practice," K. Fidler, 6.45 p.m.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS

Fri., Feb. 25th.—Mining Institute, Newcastle upon Tyne, " Investigation of Blistering and Mildew of Motor Cars in Course of Transport by Sea to Australia," E. A. Shipley, 6.15 p.m.

ROYAL INSTITUTION OF CHARTERED SURVEYORS

Mon., Feb. 28th.—12, Great George Street, London, S.W.1, " Historic Buildings : Their Preservation and Use," J. Chuer Ede, 5.30 p.m.

SOCIETY OF INDUSTRIAL ENGINEERS

Fri., Feb. 25th.—Engineers' Club, Albert Square, Manchester, " Production Control," S. Wright, 7 p.m.